EQL Report No. 16-3

# METHODS FOR SULFATE AIR QUALITY MANAGEMENT

## Volume 3

## — Appendices —

by

GLEN R. CASS

with

PAMELA S. McMURRY and JAMES E. HOUSEWORTH

EQL REPORT NO. 16-3
May 1980

Environmental Quality Laboratory
CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California 91125

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Final Report to the

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# APPENDIX A

## EMISSION SOURCE RELATED APPENDICES

# APPENDIX A1

# THE QUANTITY AND SULFUR CONTENT OF CRUDE OIL SUPPLIED TO THE SOUTH COAST AIR BASIN IN 1973

## A1.1 Introduction

In this appendix, the methods used to trace crude oil from its source to the South Coast Air Basin will be described. The purpose of this study was to assure that the amount of sulfur entering the air basin via crude oil was fully determined. Therefore, a serious attempt was made to find the sulfur content as well as the quantity of the oil delivered. This survey was nominally conducted for the year 1973, although some of the data employed came from other recent years. In the following paragraphs, a brief description of the approach used in this study will be given.

Crude oil quality varies widely from one oil field to another. In order to obtain a quantitative description of crude oil properties entering the South Coast Air Basin, the oil must be tracked to its source. Oil-producing regions of the world were subdivided into three basic categories: California oil fields, other domestic sources, and foreign crude oil supplies. These categories are convenient because different data sources are needed to assess crude oil properties from each of these three producing territories.

Smaller geographic regions within each producing category were then defined. California oil fields were subdivided into five producing regions based on geographic terrain and access to common

transportation links. Previously reported surveys of California oil use (Nehring, 1975) showed that the only non-California domestic oil producing regions important to California oil consumption were in Alaska and the Four Corners area between Utah and New Mexico. Foreign crude oils were first considered by country of origin, and then grouped into ten major geographic zones (e.g. South Pacific, Persian Gulf, etc.).

Total oil production in each major field in each producing district was determined for a base year of interest. Then sulfur content information for crude oil from each field was used to compute the total quantity of associated sulfur produced along with the oil. Sulfur and oil production data were then pooled for all fields within the producing district of interest. The distribution of crude oil production within sulfur content intervals was determined. The fraction of oil production with a sulfur content between 0.26% and 0.50% sulfur, for example, was then apparent in any producing district. Finally, a weighted average sulfur content of crude oil was determined for each sulfur content interval in each producing district. In that manner, oil supplies at the wellhead around the world were organized and stratified by sulfur content.

Next, oil shipments to the South Coast Air Basin were estimated by investigating available transportation links. California crude oil shipments to the South Coast Air Basin were estimated from local production within the Los Angeles Basin, plus waterborne commerce data and pipeline capacities.

Crude oil transfers to the entire state of California from out-of-state domestic sources and from major foreign countries were obtained by

producing district of origin for 1973. Total receipts of non-California crude oil at local harbors were determined. Unfortunately, these local harbor crude oil receipts are not resolved by state or by country of origin. Therefore, the assumption was made that the distribution of crude oil by country of origin arriving at South Coast Air Basin ports was directly proportional to that estimated for all foreign and out-of-state domestic oils received by ship in California.

By combining crude oils from California fields, out-of-state domestic sources and foreign imports, both the total quantity of crude oil and the distribution of that oil between high sulfur and low sulfur crude oils, was estimated. The details of this crude oil characterization study will now be presented. A discussion of this survey's implications for control of sulfur oxides emissions by manipulation of crude oil entering the South Coast Air Basin will then follow.

## A1.2 California Crude Oil

### A1.2.1 Characterization of Production by Sulfur Content

Table A1.1 shows the fraction of California oil production appearing within sulfur content intervals as a function of oil field location. Oil production data came from the California Division of Oil and Gas, (1974). Crude oil sulfur content data, given by the Bureau of Mines (1975b), was matched on a field-by-field basis with the state oil production figures. Then, data for all fields within each producing region were totaled. In a few cases, subfields were listed by the Bureau of Mines (1975b) which were not

TABLE A1.1

Characterization of California Crude Oils by Sulfur Content

| Producing Region and Sulfur Content Range | Total 1974 Production (thousands of barrels per year) | % of Total Production | Average Weight Percent Sulfur |
|---|---|---|---|
| I. Local Crudes Produced within the South Coast Air Basin (1974) | | | |
| A. Los Angeles Basin | | | |
| 0.00 to 0.25%S | 0.0 | 0.0 | --- |
| 0.26 to 0.50 | 1,844.3 | 1.5 | 0.44 |
| 0.51 to 1.00 | 13,854.5 | 11.0 | 0.73 |
| 1.01 to 2.00 | 96,798.2 | 77.0 | 1.48 |
| 2.01 to 3.00 | 11,231.5 | 8.9 | 2.41 |
| 3.01 to 4.00 | 1,905.1 | 1.5 | 3.08 |
| 4.01 and up | 49.0 | 0.0 | 4.43 |
| L.A. Basin subtotal | 125,682.6 | | 1.49 |
| B. Ventura Area (on-shore only) | | | |
| 0.00 to 0.25%S | 0.0 | 0.0 | --- |
| 0.26 to 0.50 | 123.7 | 0.4 | 0.40 |
| 0.51 to 1.00 | 4,486.8 | 16.3 | 0.82 |
| 1.01 to 2.00 | 18,938.5 | 68.7 | 1.10 |
| 2.01 to 3.00 | 2,593.3 | 9.4 | 2.75 |
| 3.01 to 4.00 | 497.5 | 1.8 | 3.40 |
| 4.01 and up | 944.4 | 3.4 | 4.50 |
| Ventura subtotal | 27,584.2 | | 1.08 |
| II. California Crudes Produced Outside of the South Coast Air Basin (1974) | | | |
| A. Central California Coast (District 3 minus two fields: 1)Cuyama South Main; 2)Russell Ranch Main) | | | |
| 0.00 to 0.25%S | 52.8 | 0.2 | 0.18 |
| 0.26 to 0.50 | 0.0 | 0.0 | --- |
| 0.51 to 1.00 | 35.0 | 0.1 | 0.69 |
| 1.01 to 2.00 | 73.7 | 0.2 | 1.30 |
| 2.01 to 3.00 | 16,130.9 | 54.7 | 2.30 |
| 3.01 to 4.00 | 436.9 | 1.5 | 3.66 |
| 4.01 and up | 12,781.2 | 43.3 | 4.70 |
| Central Coast subtotal | 29,510.5 | | 3.35 |
| B. San Joaquin Valley - Districts 4 & 5 plus two fields listed above | | | |
| 0.00 to 0.25%S | 11,347.3 | 9.2 | 0.21 |
| 0.26 to 0.50 | 12,030.7 | 9.8 | 0.32 |
| 0.51 to 1.00 | 67,041.2 | 54.4 | 0.81 |
| 1.01 to 2.00 | 32,791.9 | 26.6 | 1.20 |
| 2.01 to 3.00 | 0.0 | 0.0 | --- |
| 3.01 to 4.00 | 0.0 | 0.0 | --- |
| 4.01 and up | 0.0 | 0.0 | --- |
| San Joaquin Valley subtotal | 123,211.1 | | 0.8 |
| C. Northern Region subtotal | 432.3 | | --- |

itemized in the state oil and gas report. In these cases, oil production figures given in the state report were apportioned to subfields appearing in the Bureau of Mines survey in proportion to 1971 production data given by the Bureau of Mines (1975b). Fields appearing in the crude oil sulfur content survey which are now listed as abandoned by the state were excluded from our study.

Next, the year 1973 was chosen as the base year for our study.[1] Total California oil production in each of our producing regions was obtained for that year from the 59th Annual Report of the State Oil and Gas Supervisor (California Division of Oil and Gas, 1973). The oil was subdivided into quantities produced within various sulfur content intervals in proportion to the sulfur content distribution previously calculated for 1974 in Table A1.1. Oil produced from Federal offshore leases in the Ventura and Santa Barbara areas was characterized as having properties similar to onshore production from Ventura County fields appearing in the state oil and gas reports.

API gravity values were estimated for each sulfur content interval in each producing district based on data contained in a state legislative report on the cost of refining California crude oils (Joint Committee on the Public Domain, 1974a). Given an estimate of API gravity, the density, $\rho$, of the crude oil may be calculated. The relationship is

$$\frac{1178.41}{^{\circ}\text{API} + 131.5} = \rho\left(\frac{\text{lbs}}{\text{gallon}}\right) \qquad \text{(A1.1)}$$

[1] Our original intent had been to investigate the year 1974, but complete data on foreign crude oil production and shipment could be obtained only for 1973.

Then from the weight of the crude oil produced and the weight percent sulfur involved, one can calculate the total quantity of sulfur contained in each crude petroleum stock.

A1.2.2 California Crude Oil Transportation to the South Coast Air Basin

At this point we have an estimate of crude oil supplies and sulfur content at the wellhead in various locations throughout California. The next step is to determine how much of each crude oil supply is received by South Coast Air Basin refineries. The two principal transportation modes concerned were ships and pipelines.

California crude oil pipeline capacity and/or throughput data for recent years are contained in a state legislature report (Joint Committee on the Public Domain, 1974b). Information given in that report was used to estimate 1973 crude oil shipments along the Ventura to Los Angeles pipeline system, as shown in Table A1.2.

Crude oil transfers by ship from the Ventura area are given in Waterborne Commerce of the United States - 1973 (Corps of Engineers, 1973). In Table A1.3 those shipments to sea are compared to total Ventura plus Federal offshore production in 1973. The difference between production and shipment to sea is almost exactly equal to estimated pipeline flow. Therefore, the transportation modes used to bring Ventura area oils to market seem reasonably well established. Since the pipeline flows were only approximations based in part on 1972 data, it was assumed that the 1239.9 thousand barrel per year transportation discrepancy apparent for 1973 from Table A1.3 should be resolved by

TABLE A1.2

1973 Estimated Crude Oil Shipments by Pipeline from the Ventura Area to Los Angeles

| Operator[c] | Barrels per Day | |
|---|---|---|
| Shell Oil | 44,915 | (a) |
| Union Oil | 32,343 | (a) |
| Texaco | 9,450 | (b) |
| | 86,708 | |

Notes:

(a) Based on 1972 throughput data which are assumed to represent 1973 reasonably well.

(b) Enters Los Angeles through merger with pipelines from the San Joaquin Valley.

(c) Mobil Oil also operates a pipeline which connects with Shell and Texaco lines before entering Los Angeles

TABLE A1.3

Transportation Balance on Ventura and Federal Offshore Crude Oils Produced in 1973

| | Thousands of Barrels/Year | |
|---|---|---|
| | Input | Output |
| Production | 47,090 | |
| Shipped to Sea | | 14,201.7 |
| Transferred by Pipeline | | 31,648.4 |
| Totals | 47,090 | 45,850.1 |

Difference $\left( \frac{\text{In-Out}}{\text{In}} \right) = 2.6\%$

increasing estimated pipeline shipment to South Coast Air Basin refineries by an equivalent amount.

Pipelines leave the San Joaquin Valley oil fields in three directions. One link runs south to Los Angeles. Estimates of flows from the San Joaquin Valley to Los Angeles by pipeline are given in Table A1.4. A second link crosses the coastal mountain ranges and terminates on the central California coast near Estero Bay. The third system of pipelines runs north to the San Francisco Bay.

It is very difficult to estimate the destination of oil shipped through the pipelines running west from the San Joaquin Valley to the central California coast based on publicly available data. These pipelines service two of our producing districts: the San Joaquin Valley and the central California coastal oil fields. Some of the oil in these pipelines is sent to central California refineries and some is shipped to sea. The assumption was made that this pipeline network was the only means of transporting crude oil from central California coastal oil fields to market. Therefore, all central California coastal oil production was fed into this pipeline system. It was then assumed that the remaining pipeline capacity was used to ship oil from the coast to the San Joaquin Valley, or vice versa. Based on these two asusmptions, the utilization of pipelines from the San Joaquin Valley to the central California coast would appear as in Table A1.5.

The next step is to make an estimate of the portion of those domestic crude oils which are shipped to sea that later arrive by tanker in the Los Angeles area. Total <u>domestic</u> crude oil receipts

TABLE A1.4

1973 Estimated Crude Oil Shipments by Pipeline from the San Joaquin Valley to Los Angeles

| Operator | Barrels/Day | |
|---|---|---|
| Mobil | (+) 52,242 | |
| ARCO | (+) 51,300 | (a) |
| Texaco | (-) 9,450 | (b) |
| | (+) 94,092 | |

Notes:

(a) The ARCO data on oil shipped is estimated from the size of their pipeline and the relationship between pipeline size and throughput apparent from data furnished by other oil companies who gave both pipeline size, rated capacity, and actual utilization of capacity.

(b) The negative flow shown for Texaco reflects a subtraction from San Joaquin Valley oil transfer capacity to allow for the oil shipped by Texaco from the Ventura area which enters the Los Angeles area via the above San Joaquin Valley pipeline system (see Table A1.2, note (b)).

TABLE A1.5

1973 Estimated Utilization of San Joaquin Valley to Central California Coast Pipelines

Step 1. Determine Pipeline Flow:

| Operator | Barrels/Day | | Thousand Barrels/Year[b] |
|---|---|---|---|
| Standard Oil | 69,518 | (a) | 25,374.1 |
| Union Oil | 55,556 | (a) | 20,277.9 |
| Total | 125,074 | | 45,652.0 |

Step 2. Estimate Deliveries Beyond the Needs of Coastal California Oil Fields Production:

| | Thousand Barrels/Year |
|---|---|
| Pipeline Use | 45,652.0 |
| 1973 Coastal California Production | 29,595.5 |
| Excess Capacity Used for Shipment of Oil Originating Outside of Central California Coastal Region | 16,056.5 |

Step 3. Assume that the remaining 16,056.5 thousand barrels per year of crude oil shipped through these pipelines represents a transfer of oil between the San Joaquin Valley and coastal ports. The direction of flow is not known for certain.

Notes:

(a) based on 1972 data

(b) based on a 365 day year

at South Coast Air Basin harbors are given by the Corps of Engineers (1973). At several small harbors in the basin, the data available in that publication do not indicate whether crude oil transiting the port is coming in or going out. In those cases, it was assumed that crude oil was received at El Segundo and shipped to sea from Carpenteria, Huntington Beach, Ventura and Port Hueneme. On that basis, total South Coast Air Basin domestic crude oil receipts by tanker are estimated at 54,213 thousand barrels for the year 1973.

Total California refinery domestic crude oil receipts by barge and tanker for that year were 92,935 thousand barrels (Bureau of Mines, 1975a). Thus the South Coast Air Basin appears to have received 58.3% of the domestic crude oil in waterborne commerce off the California coast. The origin of the oil entering local harbors is not known explicitly. Therefore, we will first create a pool of domestic oil that is likely to be in waterborne commerce off the California coast. Then a representative cross section of 58.3% of that oil will be brought into South Coast Air Basin refineries, a quantity sufficient to match total domestic crude oil port receipts.

From our previous discussions, it is clear that 14,201.7 thousand barrels per year of crude oil with Ventura area characteristics is shipped to market by sea. Likewise, waterborne commerce data (Corps of Engineers, 1973) show a transshipment of 9,567.9 thousand barrels per year of Los Angeles Basin crude oil by tanker. Crude oil received in California from Alaska amounted to 46,200 thousand barrels per year in 1973 (Nehring, 1975). These known sources of tanker shipments

account for 69,969.6 thousand barrels per year of the 92,935 thousand barrels of domestic oil sought to form our California coastal commerce pool. The remaining shipments to sea came either from the San Francisco area or from the pipelines terminating at ports along the central California coast. Actual crude oil shipments from central California coastal ports cannot be determined precisely. That is because the commerce data at those ports do not indicate whether the oil listed as transiting the port is coming in or going out.

Therefore, some assumptions will be made. It will be assumed that San Francisco, like Los Angeles, is a net sink for crude oil and that crude oil shipments from San Francisco are small. Therefore, the 22,965.4 thousand barrels per year needed to complete the domestic oil shipments received by tanker by California refineries will be taken from the more than ample supply of oil flowing in the San Joaquin Valley to central California coast pipelines. Only 50.3% of the flow in that pipeline system need be placed aboard tankers in order to meet this 22,965.4 thousand barrel per year flow requirement.

The characterization of the source of domestic crude oils received by tanker along the California coast is now complete. Of the 92,935 thousand barrels of domestic oil at sea, a representative cross section of 54,213 thousand barrels (58.3% of the total) was characterized as entering South Coast Air Basin ports in 1973. Pipeline data were then combined with the California oils received by ship. The resulting estimates of California crude oil receipts by South Coast Air Basin refineries are shown in Table A1.6. The sulfur content of non-California domestic crude oils will be discussed next.

TABLE A1.6

1973 South Coast Air Basin California Crude Oil Receipts by Sulfur Content Based on 1974 Production Weighted Average Sulfur Content Data

| Producing Region and Sulfur Content Range | 1973 Total Production (1000's barrels) | Percent of Production (1974) | Estimated Quantity Produced in 1973 (1000's barrels) | Average Percent Sulfur by Weight | 1973 + Estimated Quantity Received in SCAB (1000's barrels) | Approximate Quantity of Sulfur Contained (1000's lbs/year) | Density (pounds per barrel) |
|---|---|---|---|---|---|---|---|
| I. Local Crudes Produced within the South Coast Air Basin | | | | | | | |
| A. Los Angeles Basin | 132,194.4 | | | 1.49 | 128,207.9* | 613,878.5 | 319.81 |
| | API° | | | | | | |
| 0.00 to 0.25%S | --- | 0.0 | 0.0 | --- | 0.0 | 0.0 | --- |
| 0.26 to 0.50 | 30.1 | 1.5 | 1,939.9 | 0.44 | 1,881.4 | 2,534.6 | 306.18 |
| 0.51 to 1.00 | 29.3 | 11.0 | 14,572.3 | 0.73 | 14,132.8 | 31,761.7 | 307.86 |
| 1.01 to 2.00 | 22.5 | 77.0 | 101,813.5 | 1.48 | 98,743.2 | 469,547.6 | 321.30 |
| 2.01 to 3.00 | 21.0 | 8.9 | 11,813.4 | 2.41 | 11,457.2 | 89,644.6 | 324.66 |
| 3.01 to 4.00 | 19.2 | 1.5 | 2,003.8 | 3.08 | 1,943.4 | 19,659.3 | 328.44 |
| 4.01 and up | 18.3 | 0.0 | 51.5 | 4.43 | 49.9 | 730.7 | 330.54 |
| B. Ventura and Fed. offshore | 47,090.0 | | | 1.36 | 41,172.8** | 176,503.9 | 310.45 |
| | API° | | | | | | |
| 0.00 to 0.25%S | --- | 0.0 | 0.0 | --- | 0.0 | 0.0 | --- |
| 0.26 to 0.50 | 35.2 | 0.4 | 188.4 | 0.40 | 164.7 | 195.6 | 296.94 |
| 0.51 to 1.00 | 31.2 | 16.3 | 7,675.7 | 0.82 | 6,711.2 | 16,734.1 | 304.08 |
| 1.01 to 2.00 | 28.6 | 68.7 | 32,350.8 | 1.10 | 28,285.7 | 96,180.4 | 309.12 |
| 2.01 to 3.00 | 23.6 | 9.4 | 4,426.5 | 2.75 | 3,870.2 | 33,972.6 | 319.20 |
| 3.01 to 4.00 | 19.6 | 1.8 | 847.6 | 3.40 | 741.1 | 8,254.7 | 327.60 |
| 4.01 and up | 15.8 | 3.4 | 1,601.1 | 4.50 | 1,399.9 | 21,166.5 | 336.00 |

+ Based on receipt of 54,213 thousand barrels of domestic oil by sea. The remainder either came by pipeline or was produced in the L. A. Basin.

*122,626.5 thousand barrels stay in the L.A. Basin. 9,567.9 thousand barrels are shipped to sea. The South Coast Air Basin is then estimated to receive 58.3% of all domestic oil shipped in California commerce.

** 32,888.3 thousand barrels are piped to South Coast Air Basin refineries. 14,201.7 thousand barrels are shipped to sea. The South Coast Air Basin then estimated to receive 58.3% of all domestic oil shipped in California commerce.

TABLE A1.6 (continued)

| Producing Region and Sulfur Content Range | 1973 Total Production (1000's barrels) | Percent of Production (1974) | Estimated Quantity Produced in 1973 (1000's barrels) | Average Percent Sulfur by Weight | 1973 Estimated Quantity Received in SCAB (1000's barrels) | Approximate Quantity of Sulfur Contained (1000's lbs/year) | Density (pounds per barrel) |
|---|---|---|---|---|---|---|---|
| II. California Crudes Produced Outside of the South Coast Air Basin | | | | | | | |
| A. District 3 minus two fields: 1. Cuyama South Main 2. Russell Ranch Main | 29,595.5 | | | 3.35 | 8,684.9* | 99,808.8 | 343.32 |
| | API° | | | | | | |
| 0.00 to 0.25%S | 33.3 | 0.2 | 59.2 | 0.18 | 17.4 | 9.4 | 306.30 |
| 0.26 to 0.50 | --- | 0.0 | 0.0 | --- | 0.0 | 0.0 | --- |
| 0.51 to 1.00 | 31.2 | 0.1 | 29.6 | 0.69 | 8.7 | 18.3 | 304.08 |
| 1.01 to 2.00 | 28.6 | 0.2 | 59.2 | 1.30 | 17.4 | 69.9 | 309.12 |
| 2.01 to 3.00 | 11.8 | 54.7 | 16,188.7 | 2.30 | 4,750.6 | 37,722.2 | 345.24 |
| 3.01 to 4.00 | 19.6 | 1.5 | 443.9 | 3.66 | 130.3 | 1,562.3 | 327.60 |
| 4.01 and up | 13.3 | 43.3 | 12,814.9 | 4.70 | 3,760.6 | 60,426.7 | 341.88 |
| B. San Joaquin Valley Districts 4&5 plus two fields named above | 126,768.1 | | | 0.81 | 39,055.4+ | 102,912.4 | 319.63 |
| | API° | | | | | | |
| 0.00 to 0.25%S | 35.6 | 9.2 | 11,662.7 | 0.21 | 3,593.1 | 2,234.2 | 296.10 |
| 0.26 to 0.50 | 32.2 | 9.8 | 12,423.3 | 0.32 | 3,827.4 | 3,703.7 | 302.40 |
| 0.51 to 1.00 | 25.2 | 54.4 | 68,961.8 | 0.81 | 21,246.2 | 54,354.2 | 315.84 |
| 1.01 to 2.00 | 13.3 | 26.6 | 33,720.3 | 1.20 | 10,388.7 | 42,620.3 | 341.88 |
| 2.01 to 3.00 | --- | 0.0 | 0.0 | --- | 0.0 | 0.0 | --- |
| 3.01 to 4.00 | --- | 0.0 | 0.0 | --- | 0.0 | 0.0 | --- |
| 4.01 and up | --- | 0.0 | 0.0 | --- | 0.0 | 0.0 | --- |

* 50.3% of total production is shipped to sea. The South Coast Air Basin then receives 58.3% of all domestic oil shipped to sea in California commerce.

+ 16,056.5 thousand barrels is in the central California coastal pipeline. 50.3% of this is shipped to sea. The South Coast Air Basin receives 58.3 of all domestic oil shipped to sea in California commerce. An additional 34,343.6 thousand barrels is piped to Los Angeles.

## A1.3 Domestic Crude Oils from Outside of California

### A1.3.1 Four Corners Area

Utah oil fields were used as the basis for characterizing Four Corners crude oil since most of the oil imported into California from the Four Corners area came from Utah (Nehring, 1975). Total crude oil production for 1973 was obtained from the International Petroleum Encyclopedia (McCaslin, 1974). The relative abundance of crude oils of various sulfur contents was based on data from Sulfur Content of Crude Oils (Bureau of Mines, 1975b). A rough estimate of crude oil API gravity was obtained from McCaslin (1974). Crude oil density was calculated from equation A1.1.

The amount of Four Corners oil delivered to California in 1973 is given by Nehring (1975). All of this oil was assumed to come to the South Coast Air Basin for processing since there is a direct pipeline link from the Four Corners area to Los Angeles. The Bureau of Mines (1975a) gives the amount of oil transferred to California by interstate pipeline. That pipeline flow amounts to approximately 3/4 of the Four Corners oil received. The remainder must have come to California by tank car or truck.

### A1.3.2 Alaskan Oil

Oil fields in southern Alaska were the only other important source of domestic oil supplied to California in 1973. The references used to determine total Alaskan oil production, sulfur content and API gravity are the same as described for Four Corners oil.

Nehring (1975) indicates that 46,200 thousand barrels of Alaskan crude oil was received in California in 1973. This oil was previously mentioned when constructing the pool of domestic crude oil in commerce off of the California coast. As before, it is assumed that 58.3% of these coastal shipments arrive in the South Coast Air Basin, in proportion to the fraction of total California domestic crude oil receipts arriving at local ports.

A summary of interstate domestic oil shipments received in the South Coast Air Basin in 1973 is given in Table A1.7.

## A1.4 Foreign Crude Oils

### A1.4.1 Characterization of Production by Sulfur Content - 1973

In order to describe foreign imports to the South Coast Air Basin, the crude oils from all of the non-Communist oil producing nations were first characterized by sulfur content. Total production, by country, was obtained from the Minerals Yearbook (Bureau of Mines, 1975a). The relative distribution of crude oil production between crude oils of various sulfur contents was computed for major oil fields in each country from 1971 data given in Sulfur Content of Crude Oils (Bureau of Mines, 1975b). The relative distribution of sulfur contents calculated from major oil fields in each country was then applied to all oil production from that country in 1973.

Foreign countries were then combined into ten large geographic groups (e.g., South Pacific, Persian Gulf, etc.). Sulfur content distributions were calculated for each of these ten large geographic

TABLE A1.7

1973 South Coast Air Basin Crude Oil Receipts by Sulfur Content
of Non-California Domestic Oils

| State and Sulfur Content Range | Estimated Average API (gravity) | Total Production 1973 (1000's barrels) | % of Total Production (1973) | Average % Sulfur by weight (1973) | Imports to California 1973 (1000's barrels) | % Sulfur | Estimated Quantity Received in SCAB (1000's barrels) | Approximate Quantity of Sulfur contained in 1000's lbs/year | Estimated Average Density (lbs/barrel) |
|---|---|---|---|---|---|---|---|---|---|
| Southern Alaska | 35.0 | | | | | | | | 297.26 |
| 0.00 to 0.25%S | | 71,954.9 | 98.5 | 0.07 | 45,507.0 | 0.07 | 26,546.2 | 5,523.8 | |
| 0.26 to 0.50 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 0.51 to 1.00 | | 1,072.4 | 1.5 | 0.82 | 693.0 | 0.82 | 404.3 | 985.5 | |
| 1.01 to 2.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 2.01 to 3.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 3.01 to 4.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 4.01 and up | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| Southern Alaska subtotal | | 73,027.3 | | 0.08 | 46,200.0 | 0.08 | 26,950.5+ | 6,509.3 | |
| Utah (Four Corners) | 35.0 | | | | | | | | 297.26 |
| 0.00 to 0.25%S | | 23,501.9 | 90.4 | 0.10 | 10,847.1 | 0.10 | 10,847.1 | 3,224.4 | |
| 0.26 to 0.50 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 0.51 to 1.00 | | 306.1 | 1.2 | 0.82 | 141.3 | 0.82 | 141.3 | 344.4 | |
| 1.01 to 2.00 | | 2,192.1 | 8.4 | 1.99 | 1,011.7 | 1.99 | 1,011.7 | 5,984.7 | |
| 2.01 to 3.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 3.01 to 4.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 4.01 and up | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| Utah subtotal | | 26,000.1 | | 0.27 | 12,000.1 | 0.27 | 12,000.1* | 9,553.5 | |

+ Based on the estimate that the South Coast Air Basin receives 58.3% of all domestic oil arriving by tanker in California.

* It is assumed that all Four Corners oil imported to California is directed to Los Angeles.

groups. Then any nations in those geographic areas for which sulfur content data was not available were treated as having a sulfur content distribution in their crude oils like that of the geographic region as a whole. API gravity for each crude oil stock was calculated from data given in the International Petroleum Encyclopedia (McCaslin, 1974).

In the case of Ecuadorian crude oil, a different approach was taken to estimate crude oil sulfur content. In 1973, Ecuadorian crude oils formed a significant fraction of the total foreign oil imports to California (California Energy Resources Conservation and Development Commission, 1975). Unfortunately, the sulfur content of crude oils report (Bureau of Mines, 1975b) did not have any information on Ecuadorian crude oil. But another Bureau of Mines publication, Fuel Oils by Sulfur Content (Bureau of Mines, 1976) gave the sulfur content of Ecuadorian residual fuel oil. It looked very similar to Colombian residual fuel oil sulfur content, so it was assumed that Ecuadorian crude oil had a sulfur content similar to that of Colombian crude oil. Colombian crude oil was listed in Sulfur Content of Crude Oils (Bureau of Mines, 1975b) and had a weighted average of 0.95% sulfur. Therefore, a 1% sulfur content for Ecuadorian crude oil was assumed.

### A1.4.2 Foreign Crude Oil Transportation to the South Coast Air Basin

Most of the foreign crude oil received in California in 1973 was identified by country of origin by the California Energy Resources Conservation and Development Commission (1975), as shown in Table A1.8. However, 16% of the foreign imports were not identified by country.

TABLE A1.8

1973 Foreign Crude Oil Imports to California

| | Imports (thousands of barrels) |
|---|---|
| Saudi Arabia | 63,888 (per year) |
| Qatar | 1,635 |
| United Arab Emirates | 5,593 |
| Oman | 4,053 |
| Syria Arab Republic | 300 |
| Kuwait | 1,001 |
| Iran | 9,533 |
| Indonesia | 49,716 |
| Venezuela | 6,554 |
| Ecuador | 12,935 |
| Australia | 203 |
| India | 266 |
| Japan | * |
| Trinidad and Tobago | 284 |
| Unidentified | 29,397 |
| TOTAL | 185,358 |

*Very small.

This oil was assumed to come uniformly from all of the non-Communist, oil producing nations not listed specifically as exporting to California.

All foreign crude oil was assumed to be imported by ship. Based on available waterborne commerce data ( Corps of Engineers, 1973), it was estimated that 110,315 thousand barrels of foreign crude oil entered South Coast Air Basin ports in 1973. That amounts to 59.5% of total California receipts of foreign crude oil. Therefore 59.5% of each of the foreign oils brought to California was assigned to the South Coast Air Basin crude oil pool. The results are shown in Table A1.9. While results are tabulated only for ten major geographic producing regions, the imports to California were computed on a country-by-country basis whenever possible. For that reason, the estimated sulfur content of foreign oils *received in California* from some of the major producing regions is somewhat different than the sulfur content estimated for all crude oil production *originating* in that region as a whole. This simply reflects a greater participation in California trade by some nations in a producing region than was characteristic of the average of all producers in that region.

## A1.5 Summary and Discussion

Table A1.10 and Figure A1.1 summarize the estimated crude oil and associated sulfur receipts by South Coast Air Basin customers in 1973. The result is that just over one million barrels of crude oil were received daily containing 3,821 thousand pounds of sulfur per day. These crude oil receipts almost exactly match 1973 South Coast Air Basin refinery capacity of 1,006,200 bbls per stream day (Cantrell, 1973). Data on total 1973 crude oil sulfur intake by Los Angeles

# TABLE A1.9

## Foreign Crude Oil Received in the South Coast Air Basin - 1973**

| Group and Sulfur Content Range | Estimated Average API° | Total Production (1973) (1000's barrels) | % of Total Production (1973) | Average Percent Sulfur by Weight | Imports to California (1000's barrels) | % Sulfur | Estimated Quantity Received in SCAB (1000's barrels) | Approximate Quantity of Sulfur Contained (1000's lbs/year) | Estimated Average Density (lbs per barrel) |
|---|---|---|---|---|---|---|---|---|---|
| Group 1 | | | | | | | | | |
| Persian Gulf | 33.3 | | | | | | | | 300.32 |
| 0.00 to 0.25%S | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 0.26 to 0.50 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 0.51 to 1.00 | | 721,038.9 | 9.1 | 0.62 | 5,929.7 | 0.62 | 3,528.9 | 6,570.8 | |
| 1.01 to 2.00 | | 5,880,327.9 | 74.6 | 1.63 | 64,891.3 | 1.67 | 38,618.4 | 193,684.6 | |
| 2.01 to 3.00 | | 1,251,327.4 | 15.9 | 2.65 | 19,854.5 | 2.75 | 11,815.9 | 97,585.2 | |
| 3.01 to 4.00 | | 30,628.8 | 0.4 | 3.68 | 120.4 | 3.68 | 71.7 | 792.4 | |
| 4.01 and up | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| Group 1 subtotal | | 7,883,323.0 | | 1.71 | 90,795.9 | 1.83 | 54,034.9 | 298,633.0 | |
| Group 2 (Israel, Turkey, Syria, Egypt) | 29.0 | | | | | | | | 308.37 |
| 0.00 to 0.25%S | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 0.26 to 0.50 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 0.51 to 1.00 | | 8,711.4 | 5.6 | 0.84 | 60.7 | 0.84 | 36.1 | 93.5 | |
| 1.01 to 2.00 | | 146,407.6 | 94.4 | 1.69 | 1,021.7 | 1.68 | 608.0 | 3,149.8 | |
| 2.01 to 3.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 3.01 to 4.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 4.01 and up | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| Group 2 subtotal | | 155,119.0 | | 1.64 | 1,082.4 | 1.64 | 644.1 | 3,243.3 | |
| Group 3 Africa (North and West Coasts) | 37.0 | | | | | | | | 293.73 |
| 0.00 to 0.25%S | | 1,750,943.2 | 83.3 | 0.16 | 11,714.1 | 0.16 | 6,971.3 | 3,276.3 | |
| 0.26 to 0.50 | | 160,720.5 | 7.7 | 0.31 | 1,075.3 | 0.31 | 639.9 | 582.7 | |
| 0.51 to 1.00 | | 188,053.8 | 9.0 | 0.55 | 1,258.1 | 0.55 | 748.7 | 1,209.5 | |
| 1.01 to 2.00 | | 1,046.5 | 0.0 | 1.31 | 7.0 | 1.31 | 4.2 | 16.2 | |
| 2.01 to 3.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 3.01 to 4.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 4.01 and up | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| Group 3 subtotal | | 2,100,763.8 | | 0.21 | 14,054.1 | 0.21 | 8,364.1 | 5,084.7 | |
| Group 4 South Pacific | 35.0 | | | | | | | | 297.26 |
| 0.00 to 0.25%S | | 812,270.4 | 100.0 | 0.14 | 51,009.5 | 0.14 | 30,357.0 | 12,633.5 | |
| 0.26 to 0.50 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 0.51 to 1.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 1.01 to 2.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 2.01 to 3.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 3.01 to 4.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 4.01 and up | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| Group 4 subtotal | | 812,270.4 | | 0.14 | 51,009.5 | 0.14 | 30,357.0 | 12,633.5 | |
| Group 5 S.A., Carib.Coast | 27.6 | | | | | | | | 311.08 |
| 0.00 to 0.25%S | | 17,749.6 | 1.0 | 0.10 | 99.8 | 0.10 | 59.4 | 18.5 | |
| 0.26 to 0.50 | | 15,307.1 | 1.3 | 0.45 | 79.9 | 0.46 | 47.6 | 68.1 | |
| 0.51 to 1.00 | | 144,244.4 | 10.2 | 0.80 | 830.4 | 0.81 | 494.2 | 1,245.3 | |
| 1.01 to 2.00 | | 410,412.6 | 28.9 | 1.50 | 2,227.7 | 1.49 | 1,325.8 | 6,145.2 | |
| 2.01 to 3.00 | | 800,129.9 | 56.4 | 2.40 | 4,294.2 | 2.41 | 2,555.6 | 19,159.4 | |
| 3.01 to 4.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 4.01 and up | | 30,388.1 | 2.1 | 5.54 | 163.7 | 5.54 | 97.4 | 1,678.6 | |
| Group 5 subtotal | | 1,418,231.7 | | 2.00 | 7,695.7 | 1.99 | 4,580.0 | 28,315.1 | |
| Group 6 West. S. A. | 33.0 | | | | | | | | 300.87 |
| 0.00 to 0.25%S | | 17,485.0 | 6.2 | 0.12 | 36.9 | 0.12 | 22.0 | 7.9 | |
| 0.26 to 0.50 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 0.51 to 1.00 | | 266,737.1 | 93.8 | 1.00+ | 14,289.8 | 1.00+ | 8,504.2 | 25,586.6 | |
| 1.01 to 2.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 2.01 to 3.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 3.01 to 4.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 4.01 and up | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| Group 6 subtotal | | 284,222.1 | | 0.95 | 14,326.7 | 1.00 | 8,526.2 | 25,594.5 | |
| Group 7 Europe | 33.0 | | | | | | | | 300.87 |
| 0.00 to 0.25%S | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 0.26 to 0.50 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 0.51 to 1.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 1.01 to 2.00 | | 114,182.7 | 100.0 | 1.38* | 763.9 | 1.38* | 454.6 | 1,887.6 | |
| 2.01 to 3.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 3.01 to 4.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 4.01 and up | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| Group 7 subtotal | | 114,182.7 | | 1.38* | 763.9 | 1.38* | 454.6 | 1,887.6 | |

+ Ecuadorian crude oil sulfur content assumed to be approximately same as Columbian crude oil.

* Sulfur data subject to great doubt.

** Based on receipt of a representative cross section of California's foreign crude oil imports at South Coast Air Basin ports in 1973.

# TABLE A1.9
# (continued)

| Group and Sulfur Content Range | Estimated Average API° | Total Production (1973) (1000's barrels) | % of Total Production (1973) | Average Percent Sulfur by Weight | Imports to California (1000's barrels) | % Sulfur | Estimated Quantity Received in SCAB (1000's barrels) | Approximate Quantity of Sulfur Contained (1000's lbs/year) | Estimated Average Density (lbs/barrel) |
|---|---|---|---|---|---|---|---|---|---|
| Group 8 | | | | | | | | | |
| Mexico | 27.0 | | | | | | | | 312.26 |
| 0.00 to 0.25%S | | 8,690.5 | 4.5 | 0.10 | 58.1 | 0.10 | 34.6 | 10.8 | |
| 0.26 to 0.50 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 0.51 to 1.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 1.01 to 2.00 | | 109,190.1 | 57.0 | 1.77 | 730.5 | 1.77 | 434.7 | 2,402.6 | |
| 2.01 to 3.00 | | 4,576.3 | 2.4 | 2.57 | 30.6 | 2.57 | 18.2 | 146.1 | |
| 3.01 to 4.00 | | 48,049.4 | 25.1 | 3.66 | 321.4 | 3.66 | 191.3 | 2,186.3 | |
| 4.01 and up | | 20,975.3 | 11.0 | 5.19 | 140.3 | 5.19 | 83.5 | 1,353.2 | |
| Group 8 subtotal | | 191,481.6 | | 2.56 | 1,280.9 | 2.56 | 762.3 | 6,099.0 | |
| Group 9 | | | | | | | | | |
| Canada | 36.0 | | | | | | | | 295.48 |
| 0.00 to 0.25%S | | 371,306.2 | 57.3 | 0.21 | 2,484.0 | 0.21 | 1,478.3 | 917.3 | |
| 0.26 to 0.50 | | 36,903.8 | 5.7 | 0.33 | 246.9 | 0.33 | 146.9 | 143.2 | |
| 0.51 to 1.00 | | 162,925.1 | 25.1 | 0.69 | 1,090.0 | 0.69 | 648.7 | 1,322.6 | |
| 1.01 to 2.00 | | 39,009.7 | 6.0 | 1.22 | 261.0 | 1.22 | 155.3 | 559.8 | |
| 2.01 to 3.00 | | 38,201.8 | 5.9 | 2.12 | 255.6 | 2.12 | 152.1 | 952.8 | |
| 3.01 to 4.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 4.01 and up | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| Group 9 subtotal | | 648,346.6 | | 0.51 | 4,337.4 | 0.51 | 2,581.3 | 3,895.7 | |
| Group 10 | | | | | | | | | |
| Japan & Taiwan | 35.0 | | | | | | | | 297.26*** |
| 0.00 to 0.25%S | | 5,717.5 | 92.3 | 0.10 | 38.2 | 0.10 | 22.7 | 6.7 | |
| 0.26 to 0.50 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 0.51 to 1.00 | | 479.5 | 7.7 | 0.52 | 3.2 | 0.52 | 1.9 | 2.9 | |
| 1.01 to 2.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 2.01 to 3.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 3.01 to 4.00 | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| 4.01 and up | | 0.0 | 0.0 | --- | 0.0 | --- | 0.0 | 0.0 | |
| Group 10 subtotal | | 6,197.0 | | 0.13 | 41.4 | 0.13 | 24.6 | 9.6 | |

***Estimated from South Pacific Group (#4).

TABLE A1.10

Summary of 1973 South Coast Air Basin
Crude Oil Receipts plus Associated Sulfur Content

| Origin of Crude Oil | Average % Sulfur by Weight | 1973 Estimated Quantity Received in SCAB (1000's barrels/yr) | 1973 Approximate Quantity of Sulfur Contained (1000's lbs/year) |
|---|---|---|---|
| Los Angeles Basin | 1.49 | 128,207.9* | 613,878.5 |
| Ventura and Federal Offshore | 1.36 | 41,172.8* | 176,503.9 |
| Central California Coast | 3.35 | 8,648.9 | 99,808.8 |
| San Joaquin Valley | 0.81 | 39,055.4 | 102,912.4 |
| California subtotal | 1.42 | 217,085.0 | 993,103.6 |
| Alaska | 0.08 | 26,950.5 | 6,509.3 |
| Utah | 0.27 | 12,000.1 | 9,553.5 |
| Domestic Import subtotal | 0.14 | 38,950.6 | 16,062.8 |
| Group 1 (Persian Gulf) | 1.83 | 54,034.9 | 298,633.0 |
| Group 2 (Remainder of Middle East) | 1.64 | 644.1 | 3,243.3 |
| Group 3 (Africa, north and west coast) | 0.21 | 8,364.1 | 5,084.7 |
| Group 4 (South Pacific) | 0.14 | 30,357.0 | 12,633.5 |
| Group 5 (South America, Caribbean Coast) | 1.99 | 4,580.0 | 28.315.1 |
| Group 6 (Western South America) | 1.00 | 8,526.2 | 25,594.5 |
| Group 7 (Europe) | 1.38 | 454.6 | 1,887.6 |
| Group 8 (Mexico) | 2.56 | 762.3 | 6,099.0 |
| Group 9 (Canada) | 0.51 | 2,581.3 | 3,895.7 |
| Group 10 (Japan & Taiwan) | 0.13 | 24.6 | 9.6 |
| Foreign Import subtotal | 1.16 | 110,329.1 | 385,396.0 |
| TOTAL | 1.20 | 366,364.7 | 1,394,562.4 |

( = 3,821 thousand pounds per day)

*Local production less estimated net exports from the basin.

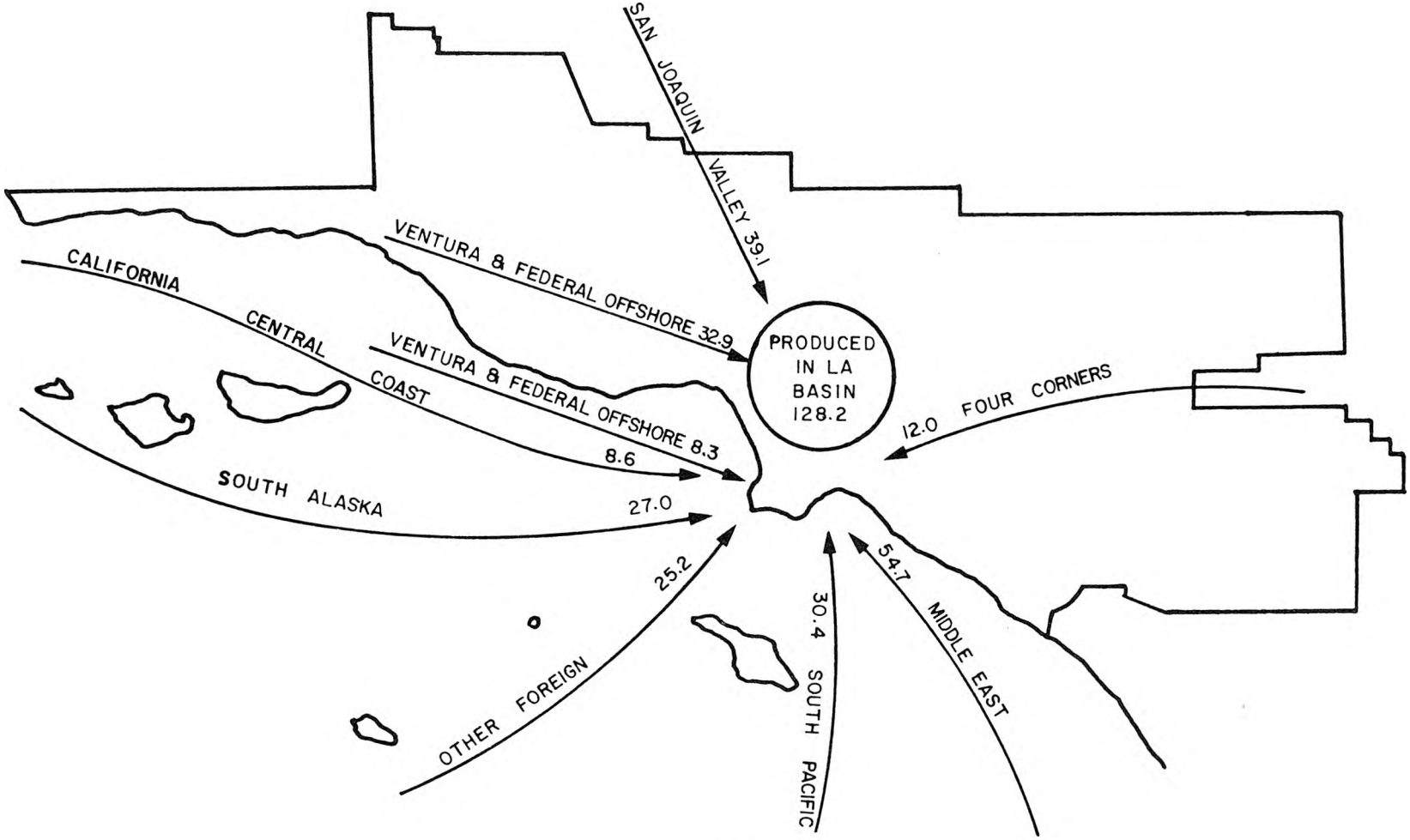



FIGURE A1.1

The Estimated Origin and Quantity of Crude Oils Received by South Coast Air Basin Customers in 1973
(Millions of Barrels per Year)

County refineries has been obtained by the Southern California Air Pollution Control District SCAPD, 1976a). Their data report that 3,551.49 thousand pounds of sulfur arrived daily at Los Angeles County refineries in feedstocks (net of unfinished oils rerun) in that year. This agrees with our independent estimate to within about 7%. There are two very small refineries excluded from the APCD survey which, if included, would probably bring these two sulfur supply estimates into even closer agreement.

In spite of the high gasoline consumption in the Los Angeles area, the South Coast Air Basin uses only a very small portion of total world oil production. This fact is easily seen in Table A1.11. Most importantly, the basin uses but a small part of the very low sulfur (less than 0.25% S) crude oil produced in the world. As seen in the trade maps of Figures A1.2 through A1.4, Japan is the major foreign customer for South Pacific region oil (generally low sulfur), buying more than ten times the amount delivered to the South Coast Air Basin from that producing region. An even smaller fraction of low sulfur African oils are imported to California. It is thus not physically impossible that sulfur input to the South Coast Air Basin could be sharply reduced by substitution of low sulfur crude oils for current high sulfur oil receipts.

However, the practical problems posed by such a fuel switching strategy look very formidable indeed. Figures A1.5 and A1.6 yield several important insights into the nature of the sulfur management problems facing Los Angeles area refineries. In the lowest sulfur

TABLE A1.11

Estimated South Coast Air Basin Crude Oil Receipts
As a Fraction of Oil Available at the Wellhead
in Various Producing Regions

| Origin of Crude Oil | Average Percent Sulfur by Weight | 1973 Estimated Quantity Consumed in SCAB (1000's barrels/yr) | Percent of total 1973 Production |
|---|---|---|---|
| Los Angeles Basin | 1.49 | 128,207.9 | 97.0% |
| Ventura and Federal Offshore | 1.36 | 41,172.8 | 87.4 |
| Central California Coast | 3.35 | 8,648.9 | 29.2 |
| San Joaquin Valley | 0.81 | 39,055.4 | 30.8 |
| California subtotal | 1.42 | 217,085.0 | 64.7% |
| Alaska (southern) | 0.08 | 26,950.5 | 36.9 |
| Utah | 0.27 | 12,000.1 | 46.2 |
| Domestic Import subtotal | 0.14 | 38,950.6 | |
| Group 1 (Persian Gulf) | 1.83 | 54,034.9 | 0.7 |
| Group 2 (Remainder of Middle East) | 1.64 | 644.1 | 0.4[a] |
| Group 3 (Africa, north and west coasts) | 0.21 | 8,364.1 | 0.4[a] |
| Group 4 (South Pacific) | 0.14 | 30,357.0 | 3.7 |
| Group 5 (South America, Caribbean Coast) | 1.99 | 4,580.0 | 0.3 |
| Group 6 (Western South America) | 1.00 | 8,526.2 | 3.0 |
| Group 7 (Europe) | 1.38 | 454.6 | 0.4[a] |
| Group 8 (Mexico) | 2.56 | 762.3 | 0.4[a] |
| Group 9 (Canada) | 0.51 | 2,581.3 | 0.4[a] |
| Group 10(Japan & Taiwan) | 0.13 | 24.6 | 0.4[a] |
| Foreign Import subtotal | 1.16 | 110,329.1 | |
| TOTAL | 1.20 | 366,364.7 | |

Note: (a) Crude oil coming to the South Coast Air Basin from undesignated countries of origin was distributed amongst all producing regions whose exports to California were not known explicitly.

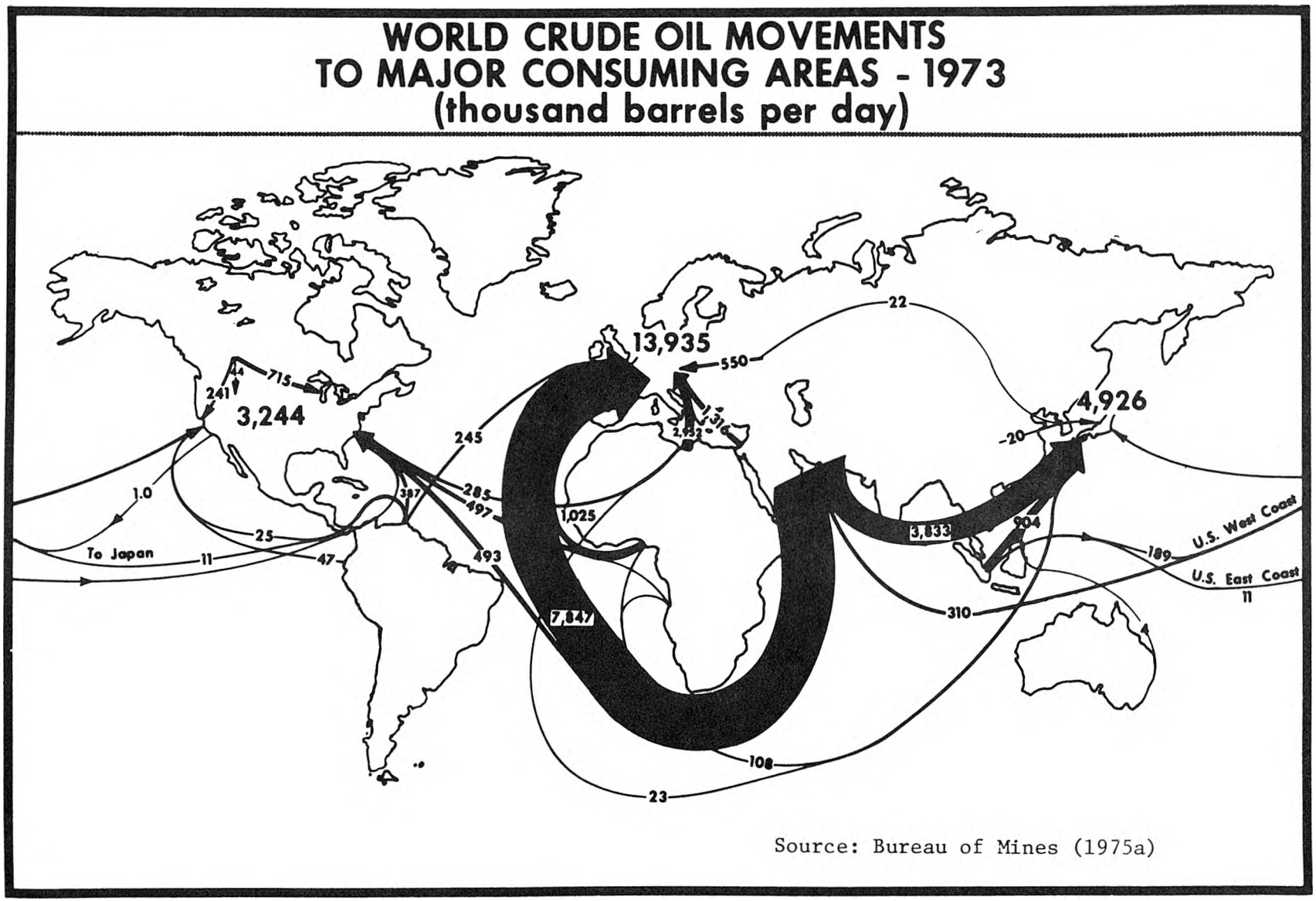

WORLD CRUDE OIL MOVEMENTS
TO MAJOR CONSUMING AREAS - 1973
(thousand barrels per day)
13,935
4,926
3,244
7,847
3,833
1,025
2,432
1,316
715
241
550
22
245
285
497
387
493
25
47
11
1.0
To Japan
20
204
189
U.S. West Coast
U.S. East Coast
11
310
108
23
Source: Bureau of Mines (1975a)

FIGURE A1.2

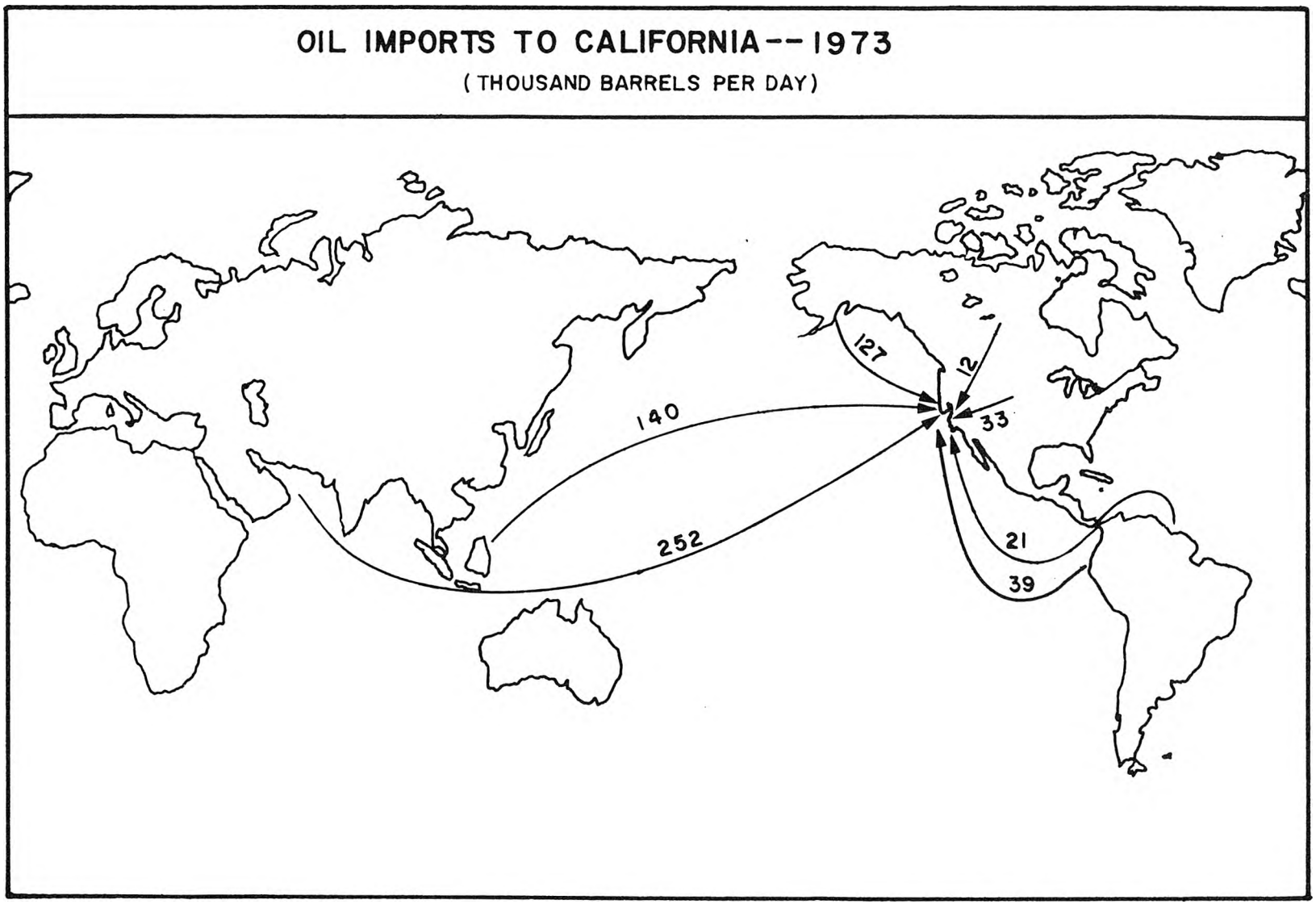

OIL IMPORTS TO CALIFORNIA--1973
(THOUSAND BARRELS PER DAY)
127
12
140
33
252
21
39

FIGURE A1.3

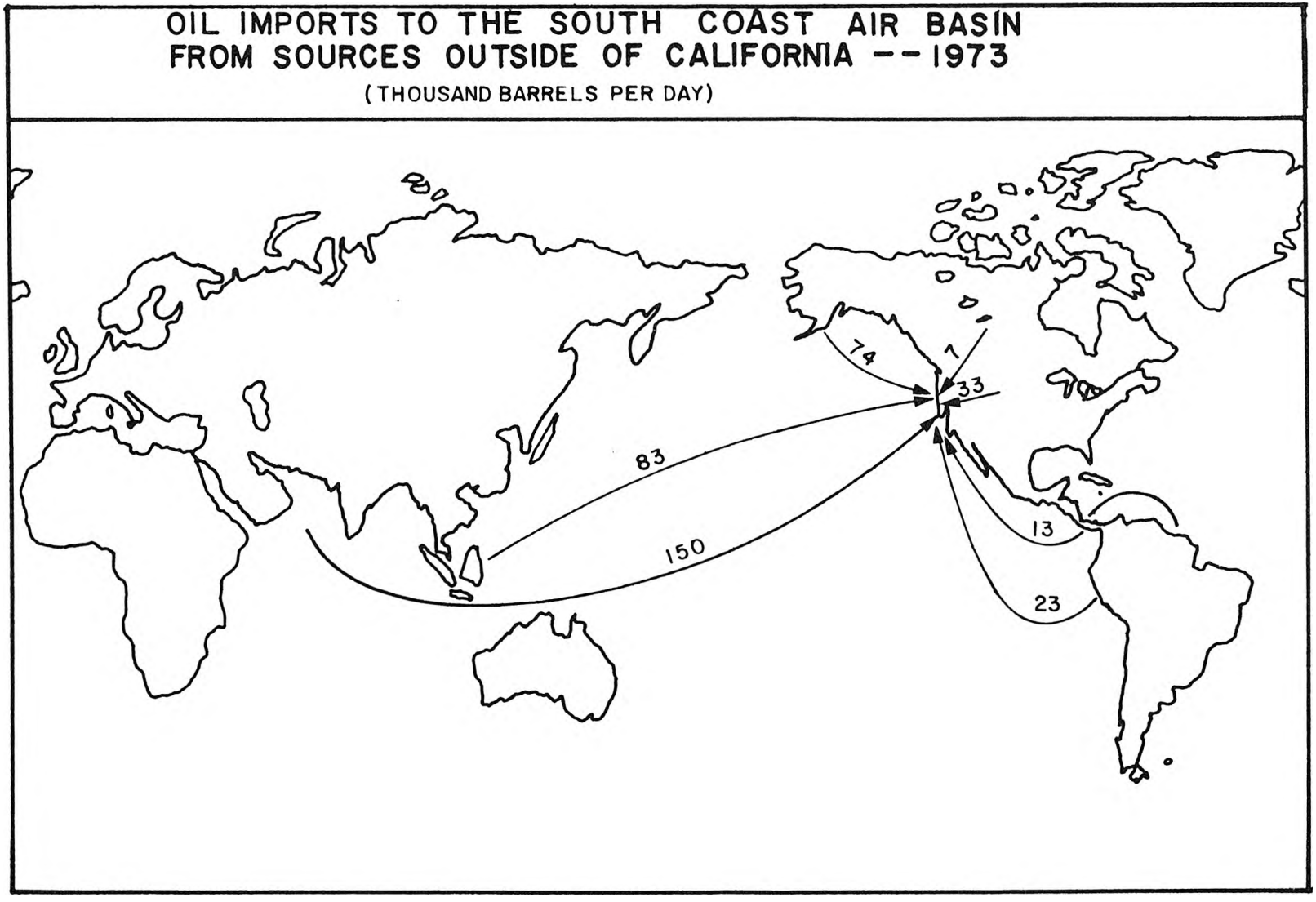

OIL IMPORTS TO THE SOUTH COAST AIR BASIN
FROM SOURCES OUTSIDE OF CALIFORNIA -- 1973
(THOUSAND BARRELS PER DAY)
74
1
33
83
150
13
23

FIGURE A1.4

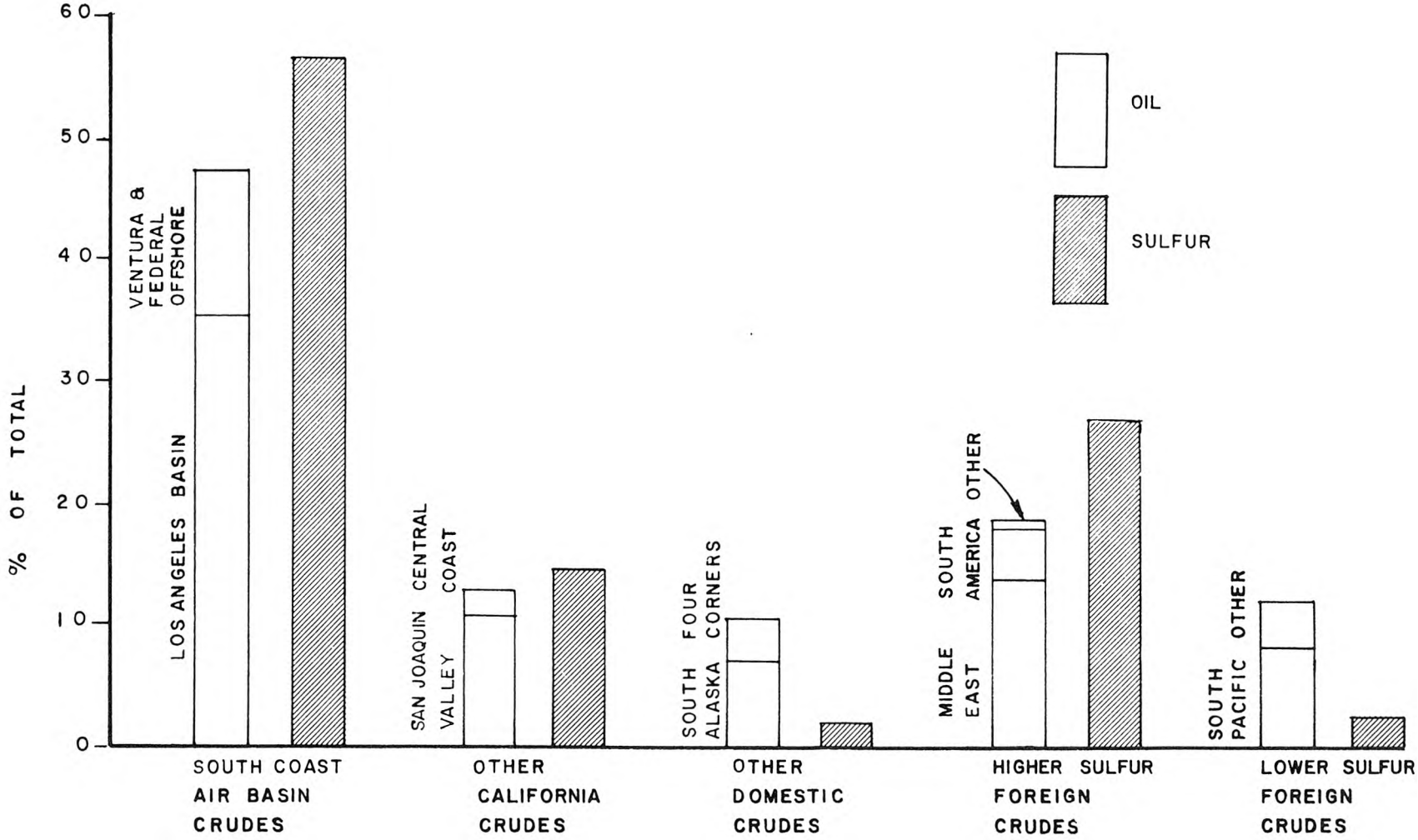



FIGURE A1.5

Fraction of Crude Oil and Sulfur coming to the South Coast Air Basin from Various Oil Producing Regions of the World-1973

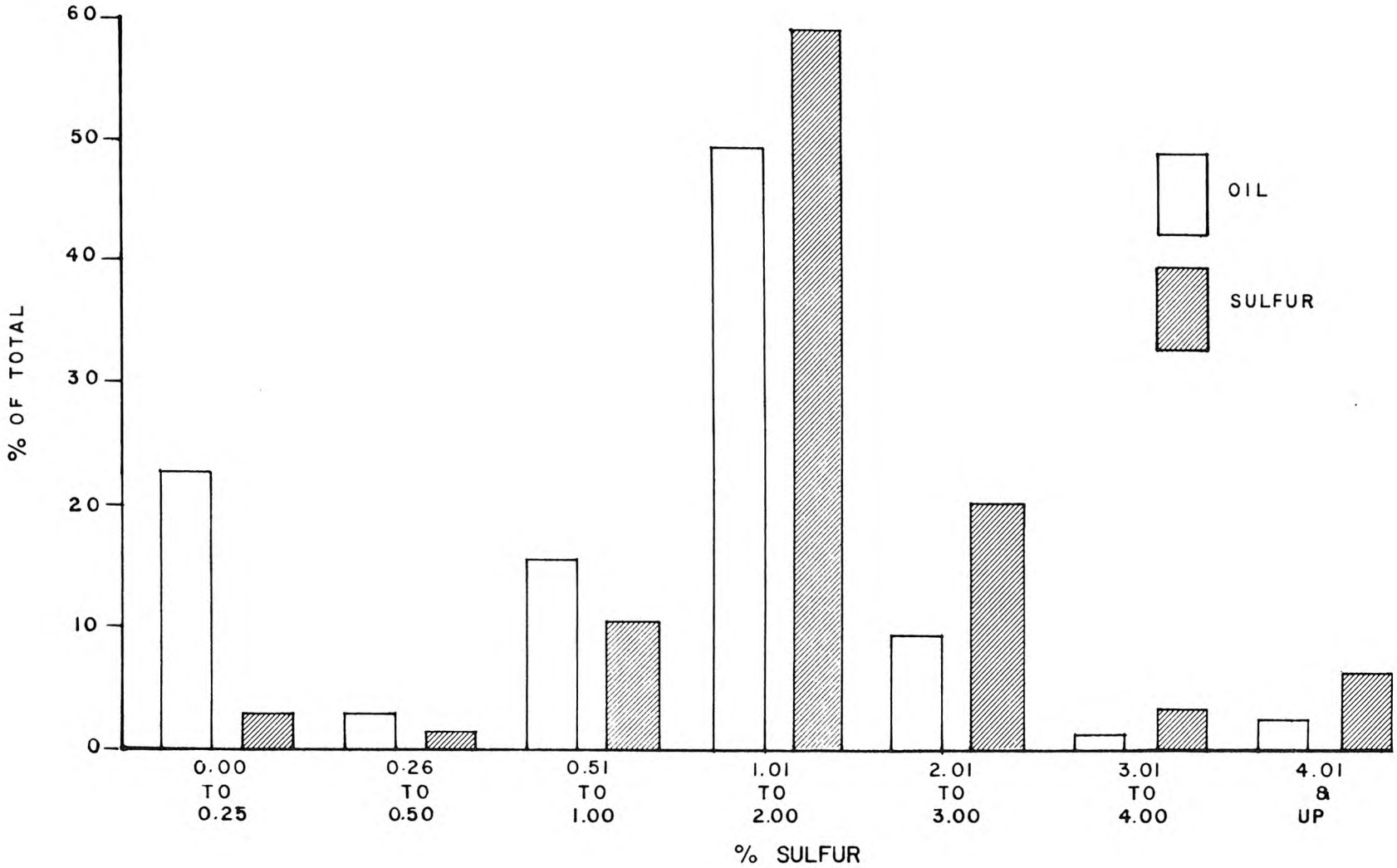



FIGURE A1.6

The Distribution of Crude Oils by Sulfur Content Received in the South Coast Air Basin in 1973

category (<0.25% S) 22% of the total oil contributes only 2% to the total sulfur burden on basin oil refineries, while in the 2.01% and higher sulfur categories, 12% of the total oil contributes 28.5% of the sulfur. Even so, the major portion of sulfur supply to the air basin comes from the 1.01 to 2.00% sulfur category where 49% of the total oil contributes 59% of the total sulfur. That 1.01% to 2.00% sulfur category is dominated by local crude oils produced in the Los Angeles and Ventura oil fields. One cannot easily divert this source of supply to other ports because the supply is already landed ashore. Substantial alteration of transfer and storage facilities would be needed if that oil were to be sold elsewhere. Thus, locally produced crude oil would be difficult to displace by importation of alternate low-sulfur crude oils. The South Coast Air Basin is apparently saddled with a sulfur management problem that is not likely to be exported elsewhere as long as local crude oils are processed in local refineries.

## References for Appendix A1

Bureau of Mines (1976), Fuel Oil by Sulfur Content, Monthly, U. S. Department of the Interior, Mineral Industry Surveys, December 1976 issue.

Bureau of Mines (1975a), Minerals Yearbook, Volume I, Metals, Minerals and Fuels, 1973, Washington D.C., U. S. Government Printing Office, U. S. Department of the Interior.

Bureau of Mines (1975b), Sulfur Content of Crude Oils, by M. Carrales Jr. and R. W. Martin, Washington, D. C., U. S. Government Printing Office, U. S. Department of the Interior, Bureau of Mines Information circular 8676.

California Division of Oil and Gas (1973), 59th Annual Report of the State Oil and Gas Supervisor, Oil Gas and Geothermal Production Statistics 1973, Sacramento, California, State of California, the Resources Agency of California.

California Division of Oil and Gas (1974), 60th Annual Report of the State Oil and Gas Supervisor, Sacramento, California, State of California.

California Energy Resources Conservation and Development Commission (1975), Energy Shortage Contingency Plan, Sacramento, California, State of California.

Cantrell, A. (1973), "Annual Refining Survey", The Oil and Gas Journal, Vol 71, No. 14, April 2, 1973.

Corps of Engineers (1973), Waterborne Commerce of the United States, Calendar year 1973, Part 4, Waterways and Harbors Pacific Coast, Alaska and Hawaii, U. S. Department of the Army.

Joint Committee on the Public Domain (1974a), Cost of Refining California Crude Oil, a report of the California State Legislature, October 1974.

Joint Committee on the Public Domain (1974b), Crude Oil Pipelines in California, a report of the California State Legislature, October 1974.

McCaslin, J. C., editor (1974) International Petroleum Encyclopedia, Tulsa, Oklahoma, The Petroleum Publishing Company.

Nehring, R. (1975), Oil and Gas Supplies for California: Past and Future, Santa Monica, California, The Rand Corporation, document R-1850-CSA/RF.

Southern California Air Pollution Control District (1976a), personal communication. The District furnished an abbreviated version of their internal document entitled "Sulfur Balance - Los Angeles County Refineries - 1973".

# APPENDIX A2
# EMISSIONS ESTIMATES FOR INDIVIDUAL SOURCES

## A2.1 Methodology

This appendix describes the assembly of an inventory of sulfur oxides emissions in the central portion of the South Coast Air Basin. Estimates were made of the emissions from over two thousand five hundred stationary sources and from seven classes of mobile sources for each month of the years 1972 through 1974. A general description of the approach used in assembling this inventory will be given first, followed by a detailed description of the emission estimation procedure for each source type.

In Figure A2.1, a square area 50 miles on each edge is shown superimposed over the central portion of the South Coast Air Basin. That square has been subdivided into a system of grid cells with a two mile spacing between adjacent cell boundaries. This grid system is suitable for use in displaying sulfate air quality model results since it substantially covers those areas of the air basin for which extensive air quality data are available for model validation. For historic reasons, the grid system is also convenient for compiling and displaying a detailed sulfur oxides source emission inventory. Each two mile by two mile grid cell corresponds to a combination of four one square mile areas used by the Southern California APCD to identify point source locations. Secondly, this grid system closely matches that used by Roth, et al. (1974) to display baseline traffic counts for Los Angeles for the year 1969 which are widely used by other air quality modeling groups. An attempt will be made here to

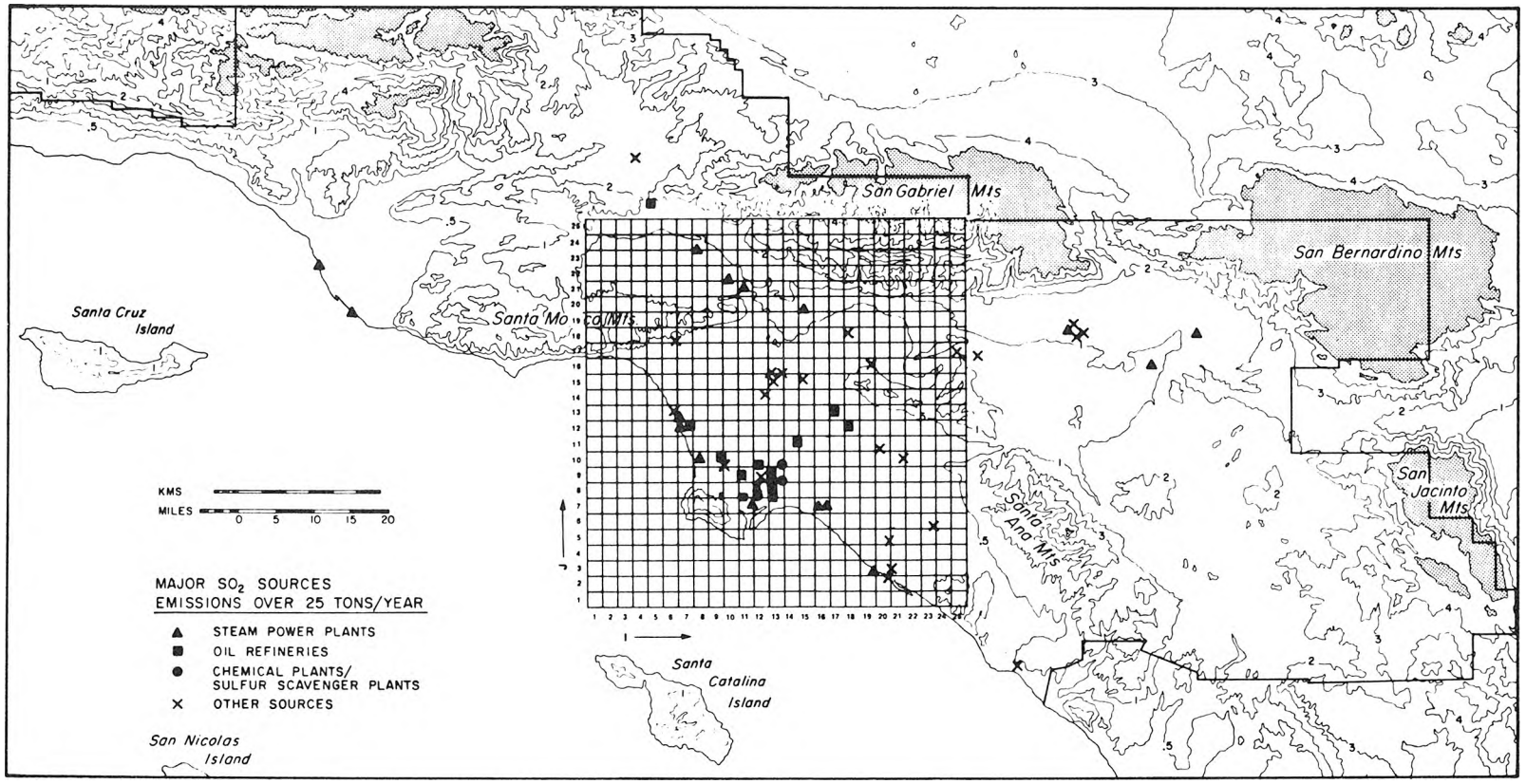



FIGURE A2.1

The Central Portion of the South Coast Air Basin
Showing the Grid System Used

develop inventory information which may assist the on-going efforts of other investigators. The grid system employed does not cover the outlying areas of the airshed. An air quality model constructed to use this inventory should thus be capable of handling the few major off-grid sources that will be detailed later in this report.

Los Angeles Air Pollution Control District (1975) historical emission summaries were consulted to obtain an idea of the relative magnitude of various classes of emission sources. The inventory was subdivided into mobile and stationary source categories, and the stationary sources were approached first. Los Angeles APCD permit files were consulted, and an APCD computerized data listing entitled "Emissions by ID Number" was selected for initial study. From this data base (hereafter referred to as the permit file) the location, ownership, equipment type and permit file emissions estimates were obtained for 2003 stationary source equipment items in Los Angeles County. Data on all equipment items listed as current sulfur oxides emitters were copied, as well as data on all boilers and all miscellaneous $NO_x$ emission sources at premises with $NO_x$ emissions of greater than 50 pounds per week. Boilers and other $NO_x$ emission sources were considered as *potential* $SO_x$ emission sources in the event that their natural gas supply was curtailed.

While emissions data were thus acquired for a large number of sources, it was quickly determined by conversation with APCD staff members that much of this permit file emission data was out-dated or reflected source operation on only one type of fuel while fuel switching from oil to gas was known to be practiced on a seasonal

basis. The permit file emissions inventory is thus best suited to serve as an equipment list around which better emissions estimates might be organized.

The equipment list was therefore subdivided into fuel burning equipment, industrial process equipment, and incinerators. The permit file emissions data for fuel burning sources were discarded, and month by month emissions from fuel burning sources were estimated from actual fuel use data available for electric utilities, oil refineries, major industries and small natural gas users, as will be described in detail later in this appendix. In the course of this investigation, several hundred additional fuel burning sources were located and added to the inventory.

Next, items of industrial process equipment emitting over one hundred pounds of $SO_x$ per week were isolated, and APCD staff engineers responsible for overseeing those sources were interviewed. As a result of this interview procedure, additional emission sources were located that were not yet a part of the computerized permit files, and better estimates were made of emissions from chemical plants, oil refineries, coke calcining kilns, glass furnaces and secondary lead smelters.

With the core of the stationary source emission data established, survey efforts were expanded beyond Los Angeles County. The source survey and staff interview procedures were repeated at the offices of the Southern California APCD-Southern Zone (formerly the Orange County APCD). Fuel burning data on power plants located outside of Los Angeles County were acquired from the Southern California Edison

Company. Major off-grid sources in San Bernardino and Riverside Counties were reviewed with the help of Southern California APCD staff. The operators of some emissions sources were contacted in order to firm-up data needed to make emission estimates.

Shortly after these emissions data from stationary sources were compiled, a detailed stationary source $SO_x$ emission inventory prepared independently by Hunter and Helgeson (1976) became available for 1974, one of our three years of interest. The two inventories were cross-checked for the year in which they overlap, with generally excellent agreement. Additions and corrections were made to our inventory to reflect certain cases in which Hunter and Helgeson's source test data were thought to present a more recent picture of source operation than was otherwise available. In most cases, however, the time sequence of emissions estimated from our fuel burning records and discussion with APCD staff were retained since they represented a longer historic period of observation, and were usually quite close to Hunter and Helgeson's estimates for the year in which both inventories overlap. Hunter and Helgeson's data for the fraction of each source's emissions evolved as $SO_3$ were adopted to supplement the APCD data base.

Finally, mobile source emissions categories for autos and light trucks, heavy duty vehicles, ships, railroads and aircraft were established. Freeway traffic counts were performed for each year of the three year period 1972 through 1974. A surface street traffic growth survey was used to update existing 1969 surface street traffic data to the years of interest. Then the traffic count

data were used to estimate motor vehicle $SO_x$ emissions for freeways and for surface streets on a spatially resolved basis. Shipping activities and railroad track mileage were assigned geographically to the grid system. Then fuel use by ships and railroads was scaled down to the grid system from the basin-wide fuel use data developed in the Energy and Sulfur Balance portion of this report (see Appendix A3). Aircraft emissions were estimated on the basis of the number of take-off and landing operations at each airport and military air base within our grid system.

## A2.2 Stationary Source Fuel Combustion Estimates for Individual Sources

Stationary source fuel combustion is the largest single activity contributing to sulfur oxides emissions in the South Coast Air Basin. While most sulfur oxides emissions arise from combustion of fuel oil, it is more convenient to classify combustion sources by their priority for receiving natural gas. This is because natural gas has been the traditional fuel of first choice within the Los Angeles basin. Fuel oil usually is burned only when gaseous fuels have been curtailed to a given class of user. By keying on the availability of gaseous fuels, one can make estimates of oil combustion by curtailed natural gas customers, even if only their priority for receiving gas is known explicitly. The source classes used to represent stationary source fuel combustion are:

- Electric Utilities
- Petroleum Refineries
- Other Interruptible Gas Customers
- Firm Natural Gas Customers

A2.2.1 Electric Utilities

Eighteen separately inventoried electric generating stations within the South Coast Air Basin are listed in Table A2.1. Thirteen of these plant sites are located within the 50 by 50 mile square grid, while the remainder are off-grid sources whose emissions will still be entered into the air quality model calculations.

Data on total monthly fuel combustion at each utility site within Los Angeles County were copied from the files of the Southern California Air Pollution Control District-Metropolitan Zone (formerly the Los Angeles Air Pollution Control District). These data were available for fuel oil, natural gas and sewage digester gas in units of barrels of equivalent fuel oil use. An APCD equivalent barrel of fuel oil was defined as having an energy content of $6.3 \times 10^6$ BTU's (Zwiacher, 1976). The APCD records draw no distinction between residual and distillate fuel oil use at power plants. The sulfur content of fuel oil burned was also recorded for each plant for each month.

All power plants located within the air basin but outside of Los Angeles County are operated by Southern California Edison Company (SCE). Data on their fuel consumption and sulfur content for each month of the years of interest were furnished by the SCE staff (Krumwiede, 1976). In the case of these Edison Company plants, both distillate and residual fuel oil use were reported, along with natural gas consumption.

Since the Southern California APCD data made up the bulk of the

TABLE A2.1

South Coast Air Basin Electric Generating Stations

| Grid Square Location East/West I | Grid Square Location North/South J | Identification | | County | 1973 Generating Capacity[a] (MEGAWATTS) Steam Generators | Gas Turbines |
|---|---|---|---|---|---|---|
| ON-GRID . . . . . | | .13 Electric Generating Stations within the 50 by 50 mile grid | | | | |
| 7 | 12 | SCE[b] | El Segundo Power Plant | Los Angeles | 1020 | |
| 8 | 10 | SCE | Redondo Power Plant | Los Angeles | 1602 | |
| 12 | 7 | SCE | Long Beach Power Plant | Los Angeles | 212 | |
| 16 | 7 | SCE | Alamitos Power Plant | Los Angeles | 1950 | 121 |
| 19 | 3 | SCE | Huntington Beach Power Plant | Orange | 870 | 121 |
| 7 | 13 | LADWP[c] | Scattergood Power Plant, El Segundo | Los Angeles | 360 | |
| 8 | 24 | LADWP | Valley Power Plant, Sun Valley | Los Angeles | 550 | |
| 11 | 7 | LADWP | Harbor Power Plant, Wilmington | Los Angeles | 425 | 80 |
| 16 | 7 | LADWP | Haynes Power Plant, Los Alamitos | Los Angeles | 1670 | |
| 10 | 22 | City of Burbank Power Plants | | Los Angeles | 175 | 40 |
| 11 | 21 | City of Glendale Power Plant | | Los Angeles | 150 | 20 |
| 15 | 20 | City of Pasadena - Glenarm | | Los Angeles | 70 | |
| 15 | 20 | City of Pasadena - Broadway | | Los Angeles | 160 | |
| OFF GRID . . . . . | | 5 Electric Generating Stations located beyond the 50 by 50 mile grid | | | | |
| -15 | 20 | SCE | Ormond Beach | Ventura | 1500 | |
| -17 | 23 | SCE | Mandalay | Ventura | 430 | 121 |
| 32 | 19 | SCE | Etiwanda | San Bernardino | 904 | 121 |
| 38 | 16 | SCE | Highgrove | San Bernardino | 154 | |
| 41 | 18 | SCE | San Bernardino | San Bernardino | 126 | |

(a) References: SCE data from Southern California Edison (1973); all other data from LAAPCD's "1974 Profile of Air Pollution Control" (Birakos, 1974).
(b) SCE - Southern California Edison Co.
(c) LADWP - Los Angeles Department of Water and Power

emissions information, energy consumption was inventoried at the APCD's stated factor of $6.3 \times 10^6$ BTU's per equivalent barrel of fuel oil. Digester gas quantities were adjusted downward from the APCD's assumed energy content of 1060 BTU's per cubic foot to an energy content of 600 BTU's per standard cubic foot based on discussions with the operators of the Hyperion treatment plant (personal communication, Rojas, 1976) which supplies digester gas to the adjacent Scattergood power plant. Energy derived from natural gas was inventoried at $6.3 \times 10^6$ BTU's per equivalent barrel for the APCD data, and at $1.06 \times 10^6$ BTU's per MCF for the Edison Company data. Distillate fuel oil identified as such by the Edison Company was recorded at the API's standard conversion factor of $5.84 \times 10^6$ BTU's per bbl, although the API gravity of this oil was so light that the energy content may be somewhat lower.

Sulfur oxides emissions from electric utility fuel burning were estimated using the following emission factors:

| Fuel Type | lbs. $SO_x$ per fuel oil equivalent barrel |
|---|---|
| Fuel Oil (residual or unidentified) | 6.384 times %S |
| Distillate Fuel Oil | 5.737 times %S |
| Digester Gas | 1.1234 |
| Natural Gas | 0.00357 |

The residual fuel oil factor used here corresponds to an API gravity of 24, in the middle of the range of residual fuel oils used at Edison Company plants for which we had the data. Residual fuel oil gravity occasionally dropped as low as API 13.5 or went as high as API 30.9. A narrower range of distillate oil gravity fluctuations was observed. Our emission factor for distillate turbine fuel is

based on an API gravity of 41.5, again taken on the middle of the range of the Edison Company's experience.

Fuel oil emission factors must be multiplied by the weight percent sulfur (%S) content of the fuel at each plant for each month. While performing this calculation, the consumption weighted average sulfur content of electric utility residual fuel oil was computed for the entire air basin for each year of interest, as shown in Table A2.2. Residual fuel oil sulfur content averaged about 14 percent below the legal limit of 0.5% sulfur by weight prevailing during the years of interest. Distillate oils used for peaking turbines were substantially below the legal limit on the sulfur content of fuels. During the period of interest, fuel oils with a sulfur content greater than 0.5% by weight were burned on occasion at the Glendale Power Plant and at SCE's Highgrove Generating Station. The Highgrove station is equipped with an experimental stack gas cleaning system which scrubs the effluent gas down to slightly less than the equivalent of burning 0.5% sulfur fuel oil. The effect of this emission control equipment was factored into the emission inventory.

The sulfur content of natural gas is so low that total fuel burning $SO_x$ emissions are insensitive to the exact choice of emission factors. The natural gas emission factor used here represents a typical United States natural gas analysis cited by the U. S. Environmental Protection Agency (1973). The $H_2S$ content of the Hyperion treatment plant's digester gas (Rojas, 1976) is used as the basis for the digester gas emission factor given for power plants.

TABLE A2.2

Consumption Weighted Sulfur Content of Utility Fuels

(As Weight Percent Sulfur)

| Year | Residual Fuel Oil (a) |
|---|---|
| 1972 | 0.420 |
| 1973 | 0.439 |
| 1974 | 0.436 |

(a) Calculated from monthly fuel use and sulfur content of fuel at all South Coast Air Basin power plants.

Table A2.3 shows the emissions and energy consumption history for three years of fuel burning behavior at all eighteen generating plants in the South Coast Air Basin. Total energy consumption is relatively constant throughout the seasons of the year, while sulfur oxides emissions peaked strongly during the winter months. This is due to substitution of fuel oil for natural gas during those months when higher priority home heating demands diverted gas from the power plants.

In Figures A2.2 and A2.3, those electric utility sulfur oxides emissions which fall within the 50 by 50 mile square grid are shown by geographic location for a typical summer and a typical winter month. The largest power plants are located adjacent to the coastline in an arc stretching from El Segundo on the north to Huntington Beach on the south. Sulfur oxides emissions from these on-grid power plants are compared to total emissions within the 50 by 50 mile square grid in Figure A2.4. During the winter months, power plants contributed about half of the man-made sulfur oxides emissions to the atmosphere. Summertime behavior varied according to the availability of natural gas and imported out-of-basin electricity. In the summer of 1972, power plant emissions were negligible, while in the summer of 1973 power plants often contributed about half of the on-grid $SO_x$ emissions from stationary sources.

Both plume rise and total emission rates are modulated by a diurnal variation in average power plant load. Los Angeles area power plant loads generally peak in the late afternoon, and reach a minimum late at night. Data on the typical diurnal variation in

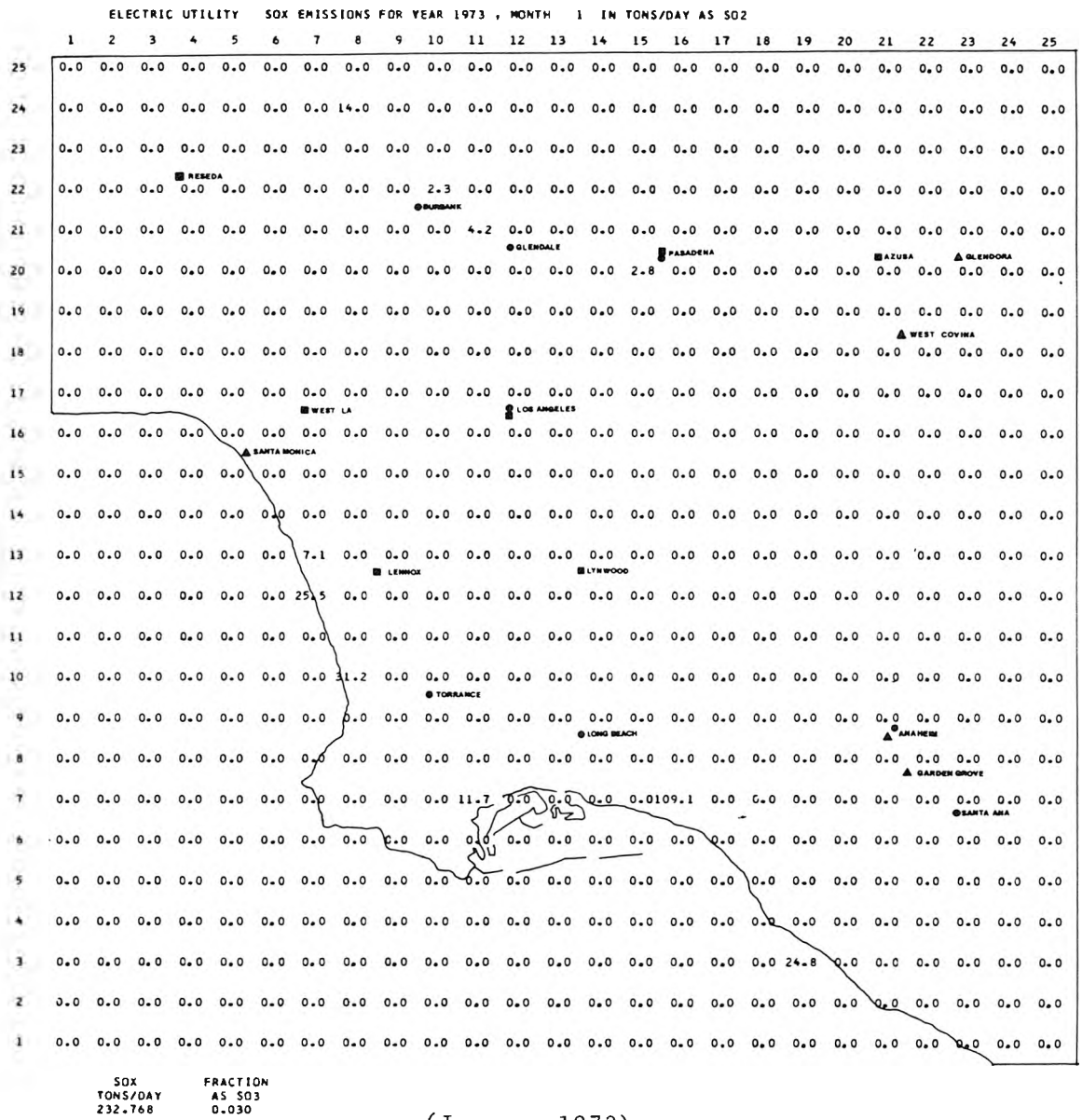
# TABLE A2.3

## Electric Utility Fuel Combustion and $SO_x$ Emissions

| YEAR | MONTH | Heat Input by Fuel Type (in $10^9$ BTUs for each month) at 18 Thermal-Electric Generating Stations in the Entire South Coast Air Basin | | | | SULFUR OXIDES EMISSIONS | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 13 Plants within 50 by 50 mile grid | | 18 Plants within entire South Coast Air Basin | |
| | | NATURAL GAS | FUEL OILS | SEWAGE DIGESTER GAS | TOTAL HEAT INPUT | TONS | TONS/DAY | TONS | TONS/DAY |
| 1972 | JAN | 5501.84 | 40768.24 | 15.92 | 46286.00 | 6660.80 | 214.86 | 8388.61 | 270.60 |
| | FEB | 19314.41 | 20292.99 | 16.06 | 39623.44 | 3580.46 | 123.46 | 4285.50 | 147.78 |
| | MAR | 25005.89 | 14424.92 | 18.35 | 39449.16 | 2590.34 | 83.56 | 3110.72 | 100.35 |
| | APR | 30145.43 | 4312.69 | 22.31 | 34480.43 | 716.89 | 23.90 | 919.53 | 30.65 |
| | MAY | 29522.13 | 6938.69 | 18.86 | 36479.67 | 1188.16 | 38.33 | 1497.81 | 48.32 |
| | JUN | 31962.71 | 4261.95 | 19.94 | 36244.60 | 719.30 | 23.98 | 899.83 | 29.99 |
| | JUL | 40964.35 | 4090.29 | 17.01 | 45071.65 | 574.60 | 18.54 | 869.85 | 28.06 |
| | AUG | 41252.14 | 6238.98 | 13.59 | 47504.70 | 998.77 | 32.22 | 1324.82 | 42.74 |
| | SEP | 32907.56 | 11636.25 | 14.80 | 44558.61 | 1871.93 | 62.40 | 2458.71 | 81.96 |
| | OCT | 18732.73 | 22462.11 | 16.60 | 41202.43 | 3931.26 | 126.81 | 4835.91 | 156.00 |
| | NOV | 7236.34 | 39060.58 | 15.73 | 46312.63 | 6718.92 | 223.96 | 8451.91 | 282.00 |
| | DEC | 5667.25 | 41200.16 | 5.45 | 46872.85 | 6980.39 | 225.17 | 8954.28 | 288.85 |
| | TOTAL | 288203.75 | 215687.81 | 194.62 | 504086.13 | 36531.81 | 99.81 | 46005.48 | 125.70 |
| 1973 | JAN | 3195.38 | 42660.68 | 18.53 | 45874.59 | 7215.82 | 232.77 | 9081.86 | 292.96 |
| | FEB | 7975.84 | 33543.60 | 18.67 | 41538.10 | 5944.82 | 212.31 | 7217.69 | 257.77 |
| | MAR | 7364.64 | 38710.22 | 20.01 | 46094.85 | 6576.00 | 212.13 | 8372.21 | 270.07 |
| | APR | 16327.59 | 21596.20 | 16.10 | 37939.88 | 3700.73 | 123.36 | 4876.11 | 162.54 |
| | MAY | 17070.47 | 25747.71 | 16.56 | 42834.73 | 4323.85 | 139.48 | 5986.04 | 193.10 |
| | JUN | 20869.75 | 29484.31 | 14.20 | 50368.25 | 4915.98 | 163.87 | 6856.49 | 228.55 |
| | JUL | 24268.87 | 28751.75 | 12.30 | 53032.90 | 4890.88 | 157.77 | 6567.14 | 211.84 |
| | AUG | 19731.02 | 33605.89 | 9.84 | 53346.74 | 5865.99 | 189.23 | 7694.29 | 248.20 |
| | SEP | 16012.41 | 30363.26 | 8.93 | 46384.60 | 5224.94 | 174.16 | 6586.20 | 219.54 |
| | OCT | 14906.33 | 35576.74 | 8.39 | 50491.45 | 5953.45 | 192.05 | 7803.86 | 251.74 |
| | NOV | 6712.68 | 43079.09 | 9.35 | 49801.12 | 6891.69 | 229.72 | 9644.05 | 321.47 |
| | DEC | 5277.04 | 30902.14 | 7.08 | 36186.25 | 4819.74 | 155.48 | 6880.05 | 221.94 |
| | TOTAL | 159712.00 | 394021.59 | 159.95 | 553893.44 | 66323.88 | 181.71 | 87565.94 | 239.91 |
| 1974 | JAN | 4363.85 | 33761.03 | 8.37 | 38133.23 | 5153.29 | 166.24 | 7247.07 | 233.78 |
| | FEB | 4334.70 | 23867.64 | 9.32 | 28211.64 | 3337.42 | 119.19 | 5172.09 | 184.72 |
| | MAR | 9189.31 | 19796.25 | 13.89 | 28999.45 | 3132.43 | 101.05 | 4356.54 | 140.53 |
| | APR | 10907.91 | 14372.89 | 10.03 | 25290.84 | 2331.93 | 77.73 | 3127.21 | 104.24 |
| | MAY | 10038.88 | 18333.29 | 11.86 | 28384.04 | 3011.93 | 97.16 | 4075.73 | 131.48 |
| | JUN | 11949.42 | 21450.18 | 11.04 | 33410.64 | 3395.66 | 113.19 | 4822.48 | 160.75 |
| | JUL | 15138.05 | 22213.34 | 0.00 | 37351.39 | 3442.02 | 111.03 | 4973.08 | 160.42 |
| | AUG | 17086.31 | 18448.59 | 6.29 | 35541.18 | 2611.24 | 84.23 | 4213.39 | 135.92 |
| | SEP | 14965.35 | 24857.00 | 4.95 | 39827.30 | 3839.27 | 127.98 | 5376.05 | 179.20 |
| | OCT | 12419.19 | 27718.69 | 3.96 | 40141.84 | 4613.60 | 148.83 | 6067.89 | 195.74 |
| | NOV | 5269.44 | 34118.86 | 7.05 | 39395.35 | 5927.96 | 197.60 | 7612.54 | 253.75 |
| | DEC | 977.33 | 39181.87 | 8.99 | 40168.18 | 6668.28 | 215.11 | 8794.50 | 283.69 |
| | TOTAL | 116639.69 | 298119.58 | 95.75 | 414855.06 | 47465.01 | 130.04 | 65838.56 | 180.38 |


(July 1973)

FIGURE A2.2




(January 1973)

FIGURE A2.3

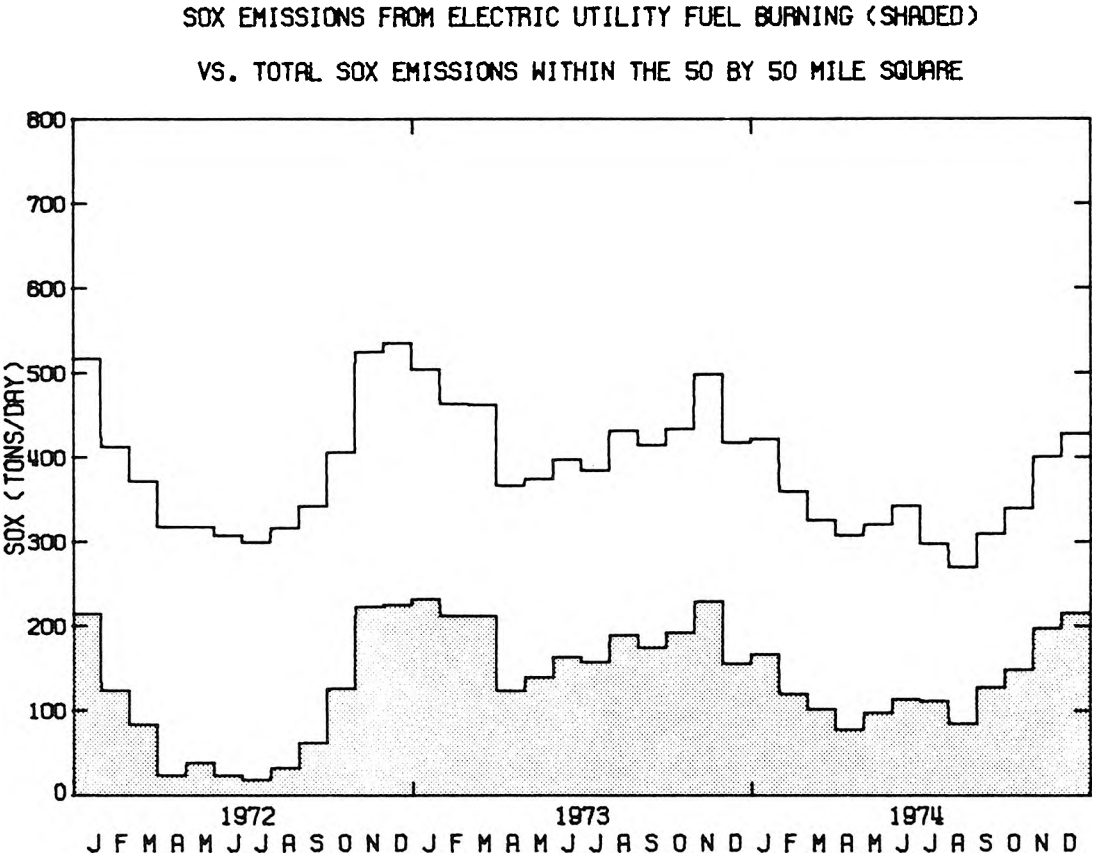

SOX EMISSIONS FROM ELECTRIC UTILITY FUEL BURNING (SHADED)
VS. TOTAL SOX EMISSIONS WITHIN THE 50 BY 50 MILE SQUARE
SOX (TONS/DAY)
800
700
600
500
400
300
200
100
0
1972
1973
1974
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

FIGURE A2.4

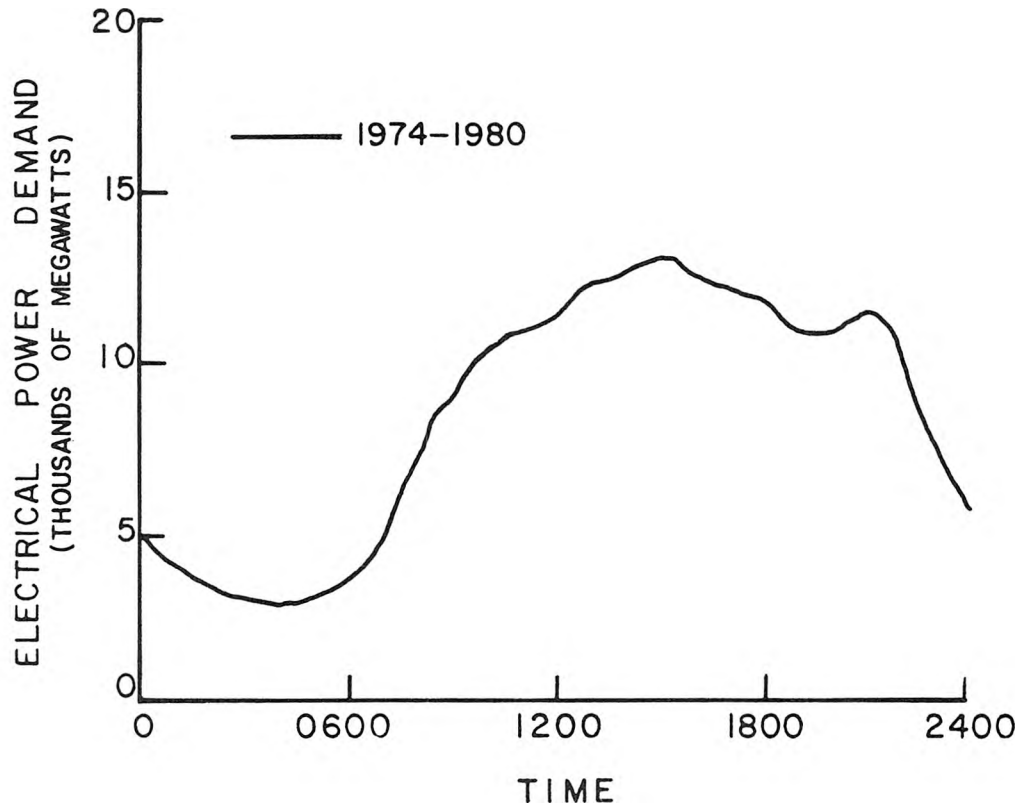
power plant loading in the Los Angeles area is given by Sjovold (1973) as shown in Figure A2.5.

A2.2.2 Refinery Fuel Burning

Petroleum refining is the second largest activity contributing to stationary source fuel combustion $SO_x$ emissions within the South Coast Air Basin. Table A2.4 lists fifteen refinery plant sites within the 50 by 50 mile square grid, all of them located in Los Angeles County. Off-grid refineries are negligible fuel burning emission sources by comparison.

Data on total monthly fuel combustion at each on-grid refinery were copied from the files of the Southern California APCD-Metropolitan Zone. Fuel consumption data were available for fuel oil, refinery gas, natural gas and sewage digester gas in units of equivalent barrels of fuel oil use. Energy use was inventoried by the methods previously detailed for electric utility fuel. Since the sulfur content of refinery gas is not given explicitly in the APCD files, the total monthly $SO_x$ emission in tons per month for each refinery were taken directly from APCD records. Back calculating the sulfur content of refinery gas by subtracting fuel oil combustion $SO_x$ emissions from total $SO_x$ emissions, it appears that refinery gases had an average sulfur content of about 10 grains per hundred cubic feet for the year 1972, and 6 to 7 grains per hundred cubic feet for 1973 and 1974. This is well below the legal limit of 50 grains per hundred cubic feet.

Table A2.5 details the emissions and energy consumption history




Projected Baseline Diurnal Power Demand on Oil Fired Power Plants in the South Coast Air Basin (From Sjovold, 1973).

FIGURE A2.5

TABLE A2.4

15 Petroleum Refineries Within the 50 by 50 Mile Study Area

| Grid Square Location East/West I | Grid Square Location North/South J | Identification | Location | 1973 Crude Oil (a) Capacity (bbl/stream day) |
|---|---|---|---|---|
| 7 | 12 | Standard Oil of California | El Segundo | 220,000 |
| 9 | 10 | Mobil Oil | Torrance | 130,000 |
| 11 | 8 | Union Oil | Wilmington | 107,000 |
| 11 | 9 | Fletcher Oil & Refining | Carson | 16,000 |
| 11 | 10 | Carson (Golden Eagle) | Carson | 7,000 |
| 12 | 10 | Shell Oil (Wilmington) | Wilmington | 88,000 |
| 12 | 8 | Champlin Petroleum | Wilmington | 30,000 |
| 12 | 8 | Texaco Inc. | Wilmington | 77,000 (b) |
| 12 | 9 | Atlantic Richfield | Carson | 173,000 |
| 12 | 10 | Shell Oil (Dominguez) | Dominguez | (c) |
| 14 | 8 | MacMillan Ring Free Oil | Signal Hill | 10,000 |
| 14 | 11 | Edgington Oil | Long Beach | 16,000 |
| 15 | 12 | Douglas Oil | Paramount | 36,000 |
| 17 | 13 | Powerline Oil | Santa Fe Springs | 30,000 |
| 18 | 12 | Gulf Oil | Santa Fe Springs | 52,000 |

(a) Reference: Cantrell (1973)

(b) Barrels per calendar day

(c) Not reported separately, presumed to be included with capacity given for Shell (Wilmington)

(d) Other very small refineries: Lunday - Thagard Oil Co. (5,200 bbl/sd) - included with industrial interruptible gas customers
Newhall Refining (6,500 bbl/sd) and
Edgington Oxnard Refinery (2,500 bbl/sd) - both off-grid.

# TABLE A2.5

Fuel Burning and $SO_x$ Emissions: 15 Petroleum Refineries within the 50 by 50 Mile Grid

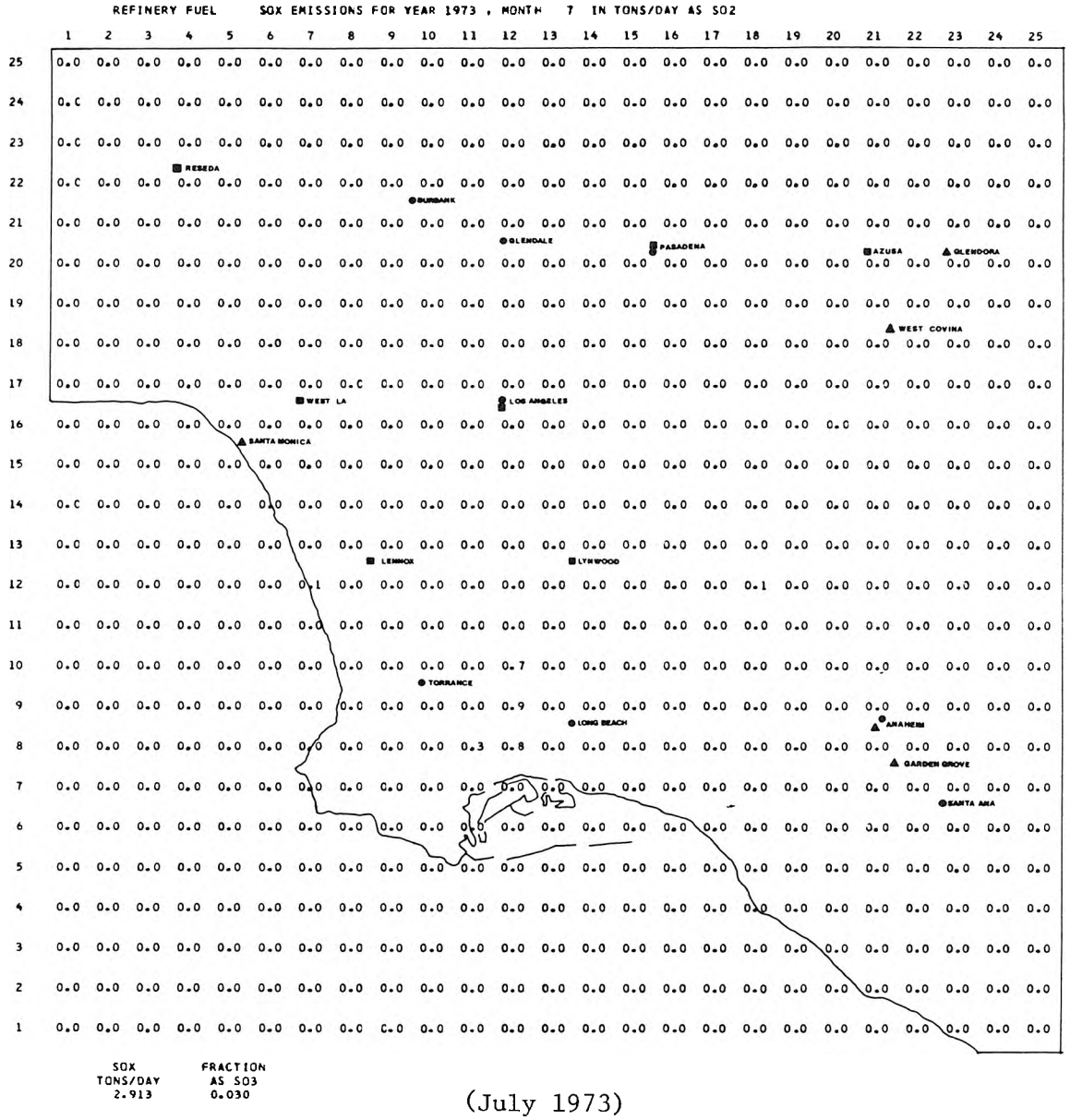
| YEAR | MONTH | HEAT INPUT BY FUEL TYPE (in $10^9$ BTUs for each month) NATURAL GAS | FUEL OILS | SEWAGE DIGESTER GAS | REFINERY GAS | TOTAL HEAT INPUT | $SO_x$ EMISSIONS tons | tons/day |
|---|---|---|---|---|---|---|---|---|
| 1972 | JAN | 2993.10 | 2725.59 | 0.0 | 9027.01 | 14745.70 | 548.40 | 17.69 |
| | FEB | 4941.21 | 501.62 | 0.0 | 8438.34 | 13881.17 | 167.50 | 5.78 |
| | MAR | 4398.57 | 164.67 | 0.0 | 8756.25 | 13319.49 | 113.40 | 3.66 |
| | APR | 4305.74 | 126.99 | 0.0 | 9026.23 | 13458.96 | 286.60 | 9.55 |
| | MAY | 5502.90 | 57.95 | 0.0 | 8721.02 | 14281.87 | 77.60 | 2.50 |
| | JUN | 5028.11 | 40.10 | 0.0 | 8747.83 | 13816.04 | 108.60 | 3.62 |
| | JUL | 4245.10 | 35.46 | 19.75 | 9856.09 | 14156.41 | 106.10 | 3.42 |
| | AUG | 4209.88 | 17.82 | 0.0 | 12744.49 | 16972.19 | 181.70 | 5.86 |
| | SEP | 5323.05 | 8.78 | 0.0 | 11718.45 | 17050.27 | 101.30 | 3.38 |
| | OCT | 5711.52 | 81.24 | 0.0 | 13041.93 | 18834.69 | 119.40 | 3.85 |
| | NOV | 2867.20 | 2419.67 | 0.0 | 12689.73 | 17976.60 | 628.40 | 20.95 |
| | DEC | 3308.00 | 2256.89 | 0.0 | 13500.73 | 19065.61 | 610.30 | 19.69 |
| | TOTAL | 52834.38 | 8436.77 | 19.75 | 126268.06 | 187559.00 | 3049.30 | |
| 1973 | JAN | 1526.32 | 3148.59 | 0.0 | 13701.33 | 18376.25 | 777.20 | 20.07 |
| | FEB | 3003.18 | 1405.77 | 0.0 | 11569.55 | 15978.50 | 378.10 | 13.50 |
| | MAR | 3221.90 | 1297.60 | 0.0 | 12461.45 | 16980.95 | 328.80 | 10.61 |
| | APR | 4385.15 | 252.64 | 0.0 | 11643.38 | 16281.17 | 127.30 | 4.26 |
| | MAY | 5309.98 | 177.40 | 0.0 | 11597.78 | 17085.17 | 123.70 | 3.99 |
| | JUN | 4303.67 | 16.87 | 0.0 | 13651.00 | 17971.54 | 111.80 | 3.73 |
| | JUL | 4934.91 | 5.90 | 0.0 | 13923.77 | 18864.58 | 90.30 | 2.91 |
| | AUG | 5285.06 | 6.67 | 0.0 | 12535.74 | 17827.46 | 66.20 | 2.14 |
| | SEP | 5955.56 | 13.16 | 0.0 | 11233.75 | 17202.47 | 71.20 | 2.37 |
| | OCT | 5617.25 | 211.88 | 0.0 | 12001.46 | 17830.59 | 124.40 | 4.01 |
| | NOV | 2379.45 | 2701.47 | 0.0 | 12011.83 | 17092.75 | 650.70 | 21.69 |
| | DEC | 2579.97 | 2607.58 | 0.0 | 12523.52 | 17711.06 | 587.70 | 18.96 |
| | TOTAL | 48502.41 | 11845.52 | 0.0 | 148854.56 | 209202.50 | 3437.40 | 9.42 |
| 1974 | JAN | 2287.15 | 3101.50 | 0.0 | 10714.77 | 16103.41 | 734.51 | 23.69 |
| | FEB | 2274.54 | 2477.19 | 0.0 | 10143.61 | 14895.33 | 585.45 | 20.91 |
| | MAR | 3903.02 | 965.09 | 0.0 | 10191.87 | 15059.98 | 235.89 | 7.61 |
| | APR | 4991.41 | 733.44 | 0.0 | 9742.18 | 15467.03 | 227.65 | 7.59 |
| | MAY | 5424.39 | 464.71 | 0.0 | 10848.32 | 16737.42 | 160.54 | 5.18 |
| | JUN | 4021.76 | 1064.20 | 0.0 | 10726.00 | 15811.96 | 278.24 | 9.27 |
| | JUL | 4603.53 | 276.25 | 0.0 | 12495.19 | 17374.98 | 134.81 | 4.35 |
| | AUG | 4886.24 | 69.40 | 0.0 | 11537.21 | 16492.86 | 99.96 | 3.22 |
| | SEP | 4579.84 | 56.86 | 0.0 | 11560.95 | 16197.65 | 113.53 | 3.78 |
| | OCT | 3721.19 | 995.91 | 0.0 | 11172.30 | 15889.39 | 323.51 | 10.44 |
| | NOV | 2441.74 | 1948.23 | 0.0 | 10908.56 | 15298.52 | 466.01 | 15.53 |
| | DEC | 1641.43 | 2603.00 | 0.0 | 11725.41 | 15969.84 | 629.90 | 20.32 |
| | TOTAL | 44776.23 | 14755.76 | 0.0 | 131766.38 | 191298.31 | 3990.00 | 10.93 |

for fuel burning activities at these oil refineries over the three years of interest. The principal fuel for powering refinery heaters and boilers is refinery gas derived from the recovered light ends of hydrocarbons being processed at the refineries. Natural gas was the second most abundant fuel, with fuel oil being used to supplement gaseous fuels, mostly during winter months when natural gas supplies were curtailed. Since the sulfur content of fuel oil is substantially greater than that of either natural gas or well-stripped refinery gas, $SO_x$ emissions from refinery fuel have historically peaked in the winter months along with fuel oil use patterns.

Figures A2.6 and A2.7 display the geographic distribution of refinery fuel burning $SO_x$ emissions for a typical summer and a typical winter month. As was the case with the power plants, the largest refineries are located adjacent to the coastline in an arc from El Segundo on the north to Long Beach on the south.

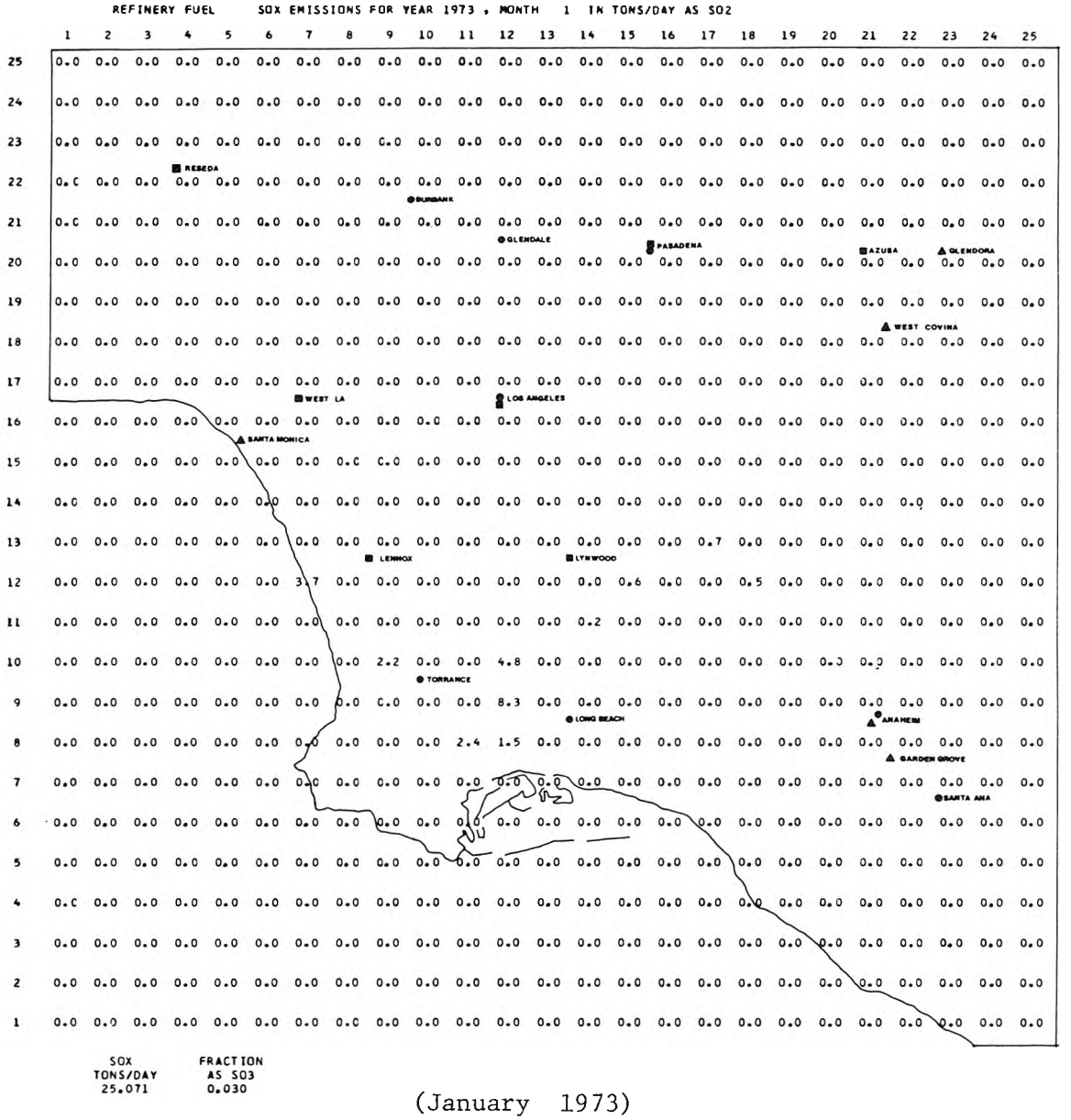
### A2.2.3 Other Interruptible Gas Customers

During the period 1972 through 1974 large commercial/institutional and industrial gas customers enjoyed a relatively high level of natural gas service, as shown in Table A2.6. Historic fuel oil combustion $SO_x$ emissions for these sources are thus very low. The California Public Utilities Commission, however, projects that increasingly severe shortages of natural gas will cause complete conversion of Southern California interruptible gas customers to the burning of alternate fuels by the year 1979 or 1980 (California Public Utilities Commission, 1976). Sulfur bearing fuel oils are




(July 1973)

FIGURE A2.6




(January 1973)

FIGURE A2.7

TABLE A2.6

Natural Gas Curtailment
of Industrial Interruptible Gas Customers*
by Southern California Gas Company
1972 - 1974

| Year | Industrial Interruptible Customer Requests for Service (MMCF/year) | Industrial Interruptible Gas Curtailed (MMCF/year) | Industrial Interruptible Gas Delivered (MMCF/year) | Deliveries as a Percentage of Requests for Service |
|---|---|---|---|---|
| 1972 | 223,733 | 19,430 | 204,303 | 91% |
| 1973 | 229,909 | 27,737 | 202,172 | 88% |
| 1974 | 224,285 | 32,320 | 191,965 | 86% |

*Including some petroleum refinery sales.
Source: 1975 California Gas Report

expected to be the principal substitute for the lost natural gas. A method for locating and characterizing energy demands by industrial and commercial interruptible gas customers is thus quite important for projection of future $SO_x$ emission levels in Los Angeles.

A complete set of spatially resolved historial data on fuel burning by interruptible gas customers is simply unavailable. Therefore, a mathematical model was developed which is capable of simulating the $SO_x$ emission impact of natural gas curtailment on the basis of a gas customer's known priority for obtaining natural gas.

Briefly, the modeling procedure is as follows. Complete data on the monthly fuel burning behavior of 134 major interruptible gas customers in Los Angeles County were copied from the files of the APCD. Data on the use of fuel oils, LPG and natural gas were obtained for these industries. When the sulfur content of fuel oil was not listed for a source in a given month, a value of 0.25% sulfur was used for distillate oil and a value of 0.40% sulfur was assumed if industrial residual fuel oil was being burned.

Next, a name and address list of nearly all of the interruptible gas customers in Los Angeles County was obtained (Zwiacher, 1976), grouped into five classes of interruption priority (curtailment blocks) based on source size. The 134 sources with complete fuel burning information were located on this list and grouped by curtailment block. Then monthly energy use and $SO_x$ emissions were accumulated to the grid system for each individual source. The monthly fuel use, by fuel type, for the average of all sources in each curtailment block was computed and retained.

Next, partial data on recent fuel burning behavior were acquired from the files of the Southern California APCD for an additional 297 interruptible gas customers. In the case of Los Angeles County sources, this took the form of one summer month's data from 1974 and one winter month's data from 1975. In the case of Orange County sources, 1974 annual average data were acquired (Zwiacher, 1976). Average heat input at these sources was computed; they were assigned to their appropriate curtailment block and located geographically on the grid. Then historic 1972 through 1974 emissions for these sources were simulated under the following assumptions:

(1) Historic average heat input and oil type consumed by each source is well represented by observed recent behavior.

(2) The gas company is an impartial supplier who curtails all customers in the same curtailment block to the same degree at the same time.

Average heat input computed for each source in each curtailment block was modulated by a seasonal trend in energy use apparent from other sources in that curtailment block for which more complete information was available. Then, sources with partial information were modeled as if their heat input demands were met by the same relative combination of fuels in a given month as was observed to have been used by the average of all similarly sized sources for which complete fuel choice data were available.

Finally, heat input at each remaining source known to be interruptible but for which no specific fuel use data were available was catalogued as requiring thermal energy at a rate equal to the

average of all sources in their curtailment block for which complete information was available. The simulation based on the average percentages of gas, LPG and oil use within a given curtailment block in a given month was again used to estimate fuel use and $SO_x$ emissions for these sources on a monthly basis.

The results of this gas curtailment simulation are shown in Table A2.7. A double check on the calculation is available since non-refinery, non-utility interruptible gas deliveries to all such customers in Los Angeles and Orange Counties are known for the year 1974 (Wood, 1977). Based on demographic data available for 1974 from the California Department of Transportation (1975), it is found that the 50 by 50 mile square grid contains 96.8% of the total employment of Los Angeles and Orange Counties. Scaling non-refinery, non-utility interruptible customer gas send-out to those counties to the employment fraction within the 50 by 50 mile grid, and subtracting non-refinery gas exchange customers from our simulation results, we obtain the gas use comparison shown in Table A2.8. Our gas curtailment model reproduced total gas use by these customers to within 6.4 percent. This gives us some confidence that the geographic distribution of $SO_x$ emissions (see Figures A2.8 and A2.9) and the total quantity of fuel oil burned is reasonably represented. Both of these pieces of information are otherwise unavailable for these years since the "energy balance" calculations presented in Appendix A3 of this report failed to balance well for distillate fuel oil. Furthermore, we now have a model which could predict the geographic distribution of fuel oil demand and $SO_x$ emissions from these sources

# TABLE A2.7

Fuel Burning Simulation Results for Other Interruptible Gas Customers Within the 50 by 50 Mile Grid
(electric utilities and refineries excluded)

| YEAR | MONTH | HEAT INPUT BY FUEL TYPE (in $10^9$ BTUs for each month) | | | | $SO_x$ EMISSIONS | |
|---|---|---|---|---|---|---|---|
| | | NATURAL GAS | FUEL OILS | LIQUFIED PETROLEUM GAS | TOTAL HEAT INPUT | tons | tons/day |
| 1972 | JAN | 10380.52 | 935.18 | 29.80 | 11345.50 | 172.22 | 5.56 |
| | FEB | 10678.30 | 225.46 | 33.95 | 10937.71 | 39.61 | 1.37 |
| | MAR | 10968.58 | 98.49 | 26.78 | 11093.84 | 18.90 | 0.61 |
| | APR | 11003.35 | 116.27 | 2.26 | 11121.87 | 22.51 | 0.75 |
| | MAY | 10832.01 | 111.29 | 2.48 | 10945.78 | 19.99 | 0.64 |
| | JUN | 10605.22 | 93.96 | 1.97 | 10701.14 | 20.17 | 0.67 |
| | JUL | 9857.30 | 66.92 | 2.35 | 9926.56 | 12.01 | 0.39 |
| | AUG | 9978.08 | 97.99 | 2.61 | 10078.67 | 19.44 | 0.63 |
| | SEP | 10427.25 | 69.70 | 2.89 | 10499.84 | 15.31 | 0.51 |
| | OCT | 10626.89 | 96.45 | 2.97 | 10726.30 | 18.22 | 0.59 |
| | NOV | 10688.20 | 383.70 | 2.64 | 11074.54 | 82.20 | 2.74 |
| | DEC | 7927.18 | 2632.59 | 256.24 | 10816.00 | 411.91 | 13.29 |
| | TOTAL | 123972.88 | 4928.00 | 366.94 | 129267.75 | 852.49 | 2.33 |
| 1973 | JAN | 9174.14 | 2532.18 | 302.44 | 12008.76 | 396.19 | 12.78 |
| | FEB | 10524.09 | 309.49 | 28.53 | 10862.11 | 62.84 | 2.24 |
| | MAR | 10625.62 | 293.98 | 15.01 | 10934.61 | 64.21 | 2.07 |
| | APR | 10925.26 | 137.84 | 12.18 | 11075.28 | 29.41 | 0.98 |
| | MAY | 10816.45 | 115.48 | 3.40 | 10935.33 | 25.25 | 0.81 |
| | JUN | 10242.52 | 41.57 | 3.14 | 10287.23 | 11.63 | 0.39 |
| | JUL | 9969.38 | 44.84 | 4.39 | 10018.61 | 11.99 | 0.39 |
| | AUG | 9673.88 | 49.00 | 4.31 | 9727.20 | 12.51 | 0.40 |
| | SEP | 10166.04 | 50.09 | 3.38 | 10219.51 | 12.80 | 0.43 |
| | OCT | 10246.13 | 108.31 | 3.21 | 10357.65 | 23.60 | 0.76 |
| | NOV | 9746.39 | 523.81 | 74.57 | 10344.77 | 107.37 | 3.58 |
| | DEC | 9337.55 | 399.60 | 78.67 | 9815.82 | 79.72 | 2.57 |
| | TOTAL | 121477.45 | 4606.19 | 533.23 | 126586.88 | 837.52 | 2.29 |
| 1974 | JAN | 8259.16 | 1527.89 | 103.91 | 9890.97 | 257.26 | 8.30 |
| | FEB | 9772.72 | 199.42 | 5.16 | 9977.30 | 44.98 | 1.61 |
| | MAR | 9782.82 | 133.62 | 2.38 | 9918.81 | 29.12 | 0.94 |
| | APR | 9594.05 | 95.17 | 2.73 | 9691.94 | 21.28 | 0.71 |
| | MAY | 9459.71 | 102.34 | 2.96 | 9565.01 | 21.49 | 0.69 |
| | JUN | 9293.45 | 149.72 | 3.40 | 9446.56 | 31.46 | 1.05 |
| | JUL | 9152.30 | 86.25 | 3.17 | 9241.73 | 19.81 | 0.64 |
| | AUG | 9332.33 | 88.62 | 1.57 | 9422.51 | 18.27 | 0.59 |
| | SEP | 9856.30 | 79.42 | 0.00 | 9935.73 | 16.19 | 0.54 |
| | OCT | 9891.12 | 149.16 | 2.49 | 10042.77 | 34.66 | 1.12 |
| | NOV | 9966.27 | 277.14 | 9.13 | 10252.54 | 61.21 | 2.04 |
| | DEC | 9219.50 | 517.80 | 28.10 | 9765.40 | 115.38 | 3.72 |
| | TOTAL | 113579.73 | 3406.55 | 165.00 | 117151.27 | 671.11 | 1.84 |

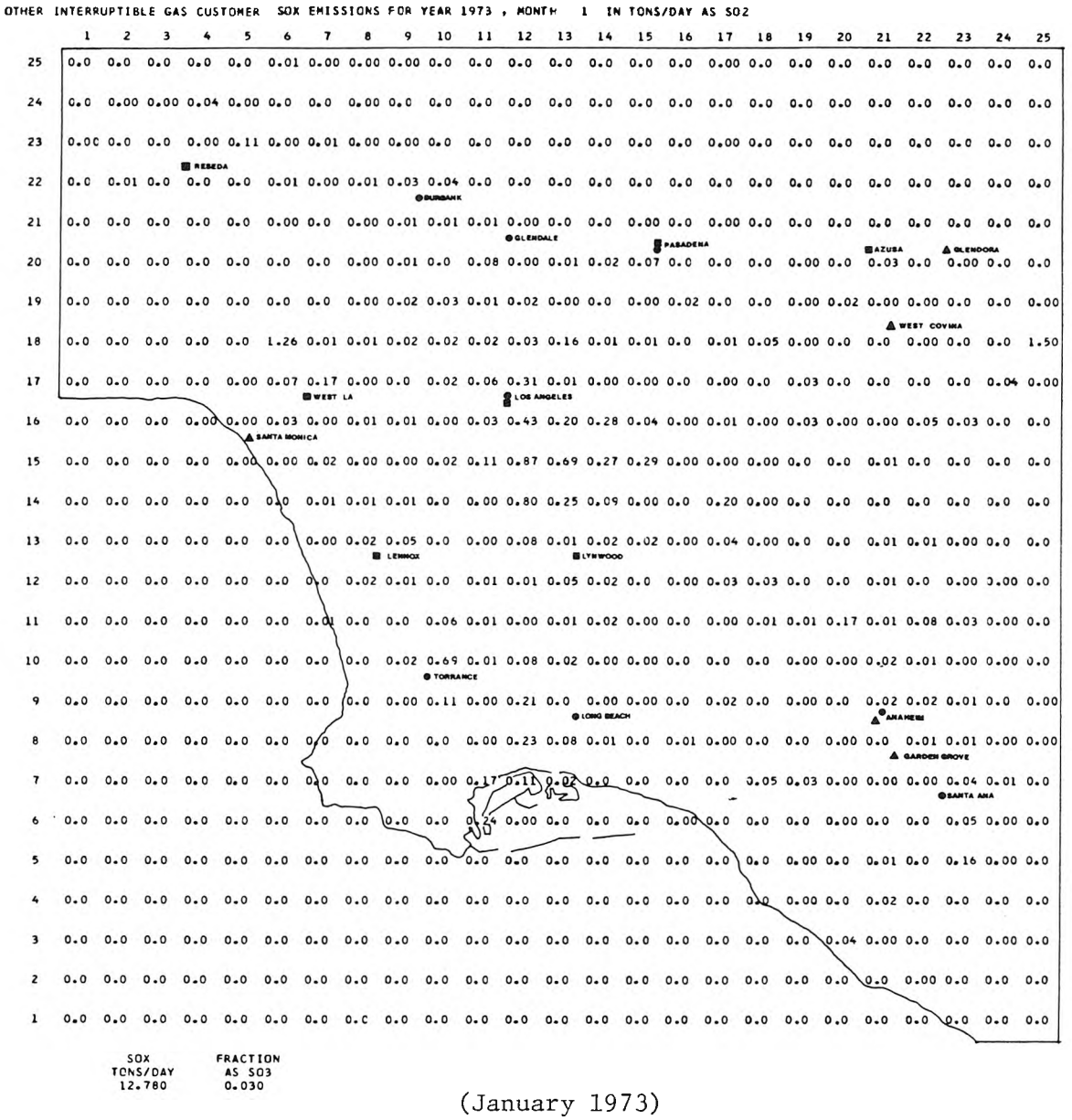
TABLE A2.8

Comparison of Interruptible Gas Use Simulation
to Gas Company Deliveries to these Customers: 1974

| | | | $10^9$ BTUs | $10^9$ BTUs |
|---|---|---|---|---|
| A. | Simulation Model - 1974 | | | |
| | 1. total gas use in 50 x 50 mile square by non-utility, non-refinery interruptible customers | | 113,579.73 | |
| | 2. less non-refinery exchange customers and process gas included in this model | (-) | 7,866.60 | |
| | 3. Industrial/Commercial/Institutional use excluding refineries and exchange customers | | 105,713.13 | 105,713.13 |
| B. | Actual Gas Company Deliveries - 1974 | | | |
| | 1. Industrial/Commercial/Institutional interruptible send-out excluding refineries and exchange customers in two counties | | | |
| | (a) So. California Gas Company | MCF | | |
| | Los Angeles County | 75,133,434 | | |
| | Orange County | 17,979,105 | | |
| | (b) Long Beach Gas Department | 3,721,671 | | |
| | Subtotal (MCF) | 96,834,210 | | |
| | Energy Content ($10^9$ BTUs) | | 102,644.26 | |
| | 2. Scale total use to the 96.8% of L.A. and Orange County employment within 50 by 50 mile square | | | |
| | $(102,644.26 \times 10^9) \cdot (0.968) =$ | | 99,359.64 | |
| | 3. Industrial/Commercial/Industrial use excluding refineries and exchange customers | | | 99,359.64 |
| C. | Excess of simulation model over actual | | | (6.4%) |


(July 1973)

FIGURE A2.8




(January 1973)

FIGURE A2.9

under anticipated 1980 conditions of complete gas curtailment.

A2.2.4 Firm Natural Gas Customers

Firm natural gas customers have the highest priority for receiving a steady gas supply. These sources are usually not equipped to burn oil as a substitute fuel. Since gas is clean-burning, historic $SO_x$ emissions from these sources have been extremely low, averaging about a third of a ton per day of $SO_x$ within the 50 by 50 mile grid.

Data on firm natural gas use in Los Angeles and Orange Counties for each month of the years 1972 through 1974 were provided by the California Air Resources Board (Wood, 1977) from Southern California Gas Company and Long Beach Gas Department reports. From this data base, domestic use and non-utility non-refinery firm industrial/commerical gas uses were isolated. The industrial/commercial gas use for each month was assigned to the grid system in proportion to estimated 1974 industrial employment within each square, while domestic gas use was allocated by estimated 1974 population density. Employment and population densities were estimated from data supplied by the California Department of Transportation (1975). This demographic data base consisted of maps showing Los Angeles Regional Transportation Study (LARTS) regional analysis zones, along with 1974 estimates of population and employment statistics within each zone. Large LARTS regional analysis zone maps were overlayed with our 50 by 50 mile grid system, and the portion of each regional analysis zone falling within each grid square was estimated graphically. Population and employment data were apportioned to the grid

system on the basis of the fraction of each regional analysis zone falling in a given square. The results are shown in Figures A2.10 and A2.11.

### A2.2.5 Total Non-Utility Fuel Combustion Emissions

For air quality modeling purposes, emissions from all non-utility fuel combustion activities will be superimposed to form a single source class. When this is done, the time history of monthly refinery, other interruptible and firm gas user $SO_x$ emissions within the 50 by 50 mile square is as shown in Figure A2.12.

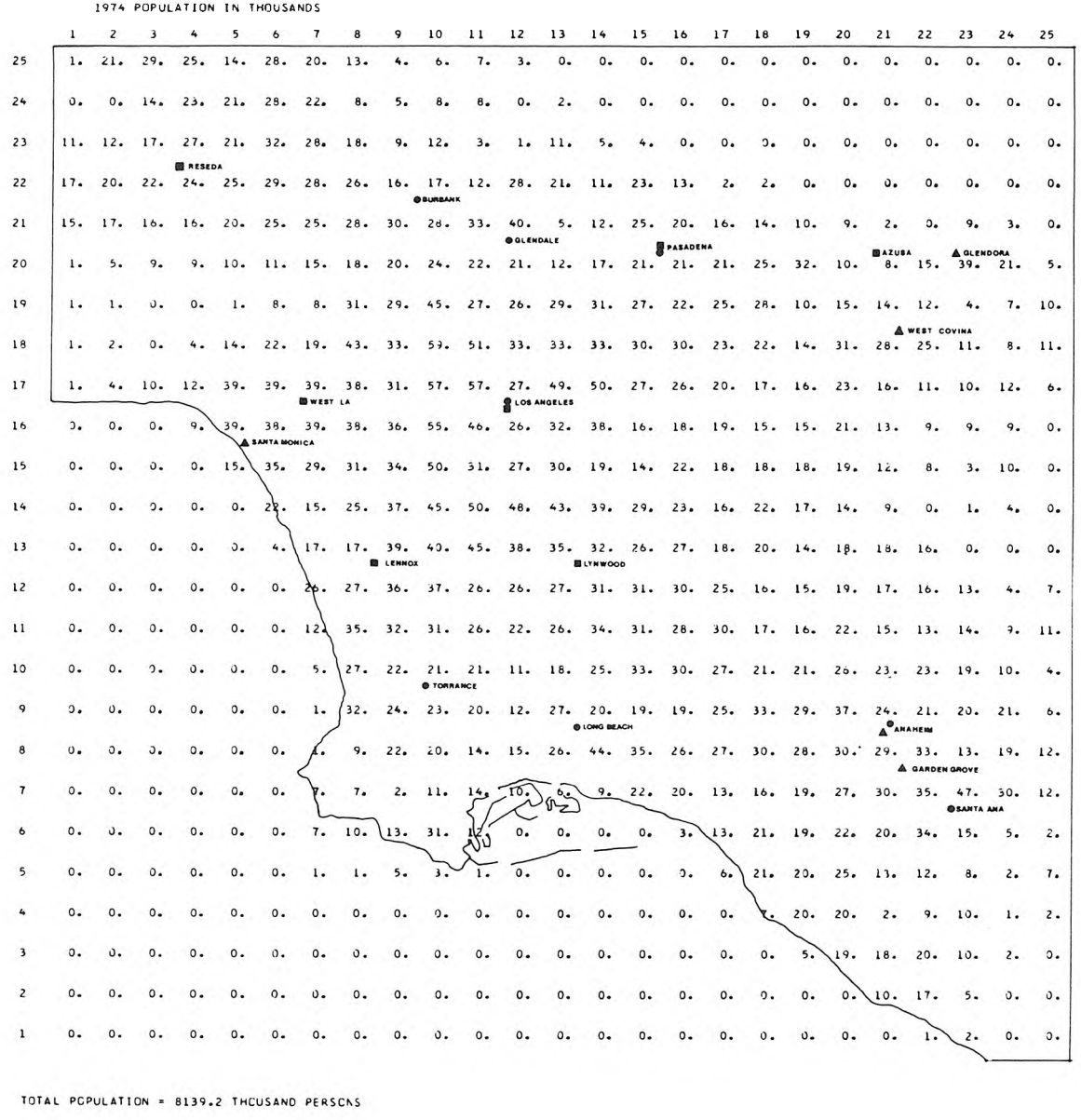
## A2.3 Chemical Plant Emissions

Sulfur oxides emissions from chemical plant operations have declined drastically during the three year period of this emissions inventory, as shown in Figure A2.13. The source classes used to describe chemical plant emissions are:

- Sulfur Recovery Plants
- Sulfuric Acid Plants
- Miscellaneous Chemical Operations

### A2.3.1 Sulfur Recovery Plants

During the year 1973, the feedstock and fuels supplied to Los Angeles area refineries contained an average of 3.7 million pounds per day of elemental sulfur bound within hydrocarbon chains (Southern California Air Pollution Control District, 1976a). As a result of the refining process, about 54 percent of this incoming sulfur burden is converted to gaseous hydrogen sulfide. If this




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 1. | 21. | 29. | 25. | 14. | 28. | 20. | 13. | 4. | 6. | 7. | 3. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 24 | 0. | 0. | 14. | 23. | 21. | 28. | 22. | 8. | 5. | 8. | 8. | 0. | 2. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 23 | 11. | 12. | 17. | 27. | 21. | 32. | 28. | 18. | 9. | 12. | 3. | 1. | 11. | 5. | 4. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 22 | 17. | 20. | 22. | 24. | 25. | 29. | 28. | 26. | 16. | 17. | 12. | 28. | 21. | 11. | 23. | 13. | 2. | 2. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |
| 21 | 15. | 17. | 16. | 16. | 20. | 25. | 25. | 28. | 30. | 28. | 33. | 40. | 5. | 12. | 25. | 20. | 16. | 14. | 10. | 9. | 2. | 0. | 9. | 3. | 0. |
| 20 | 1. | 5. | 9. | 9. | 10. | 11. | 15. | 18. | 20. | 24. | 22. | 21. | 12. | 17. | 21. | 21. | 21. | 25. | 32. | 10. | 8. | 15. | 39. | 21. | 5. |
| 19 | 1. | 1. | 0. | 0. | 1. | 8. | 8. | 31. | 29. | 45. | 27. | 26. | 29. | 31. | 27. | 22. | 25. | 28. | 10. | 15. | 14. | 12. | 4. | 7. | 10. |
| 18 | 1. | 2. | 0. | 4. | 14. | 22. | 19. | 43. | 33. | 59. | 51. | 33. | 33. | 33. | 30. | 30. | 23. | 22. | 14. | 31. | 28. | 25. | 11. | 8. | 11. |
| 17 | 1. | 4. | 10. | 12. | 39. | 39. | 39. | 38. | 31. | 57. | 57. | 27. | 49. | 50. | 27. | 26. | 20. | 17. | 16. | 23. | 16. | 11. | 10. | 12. | 6. |
| 16 | 0. | 0. | 0. | 9. | 39. | 38. | 39. | 38. | 36. | 55. | 46. | 26. | 32. | 38. | 16. | 18. | 19. | 15. | 15. | 21. | 13. | 9. | 9. | 9. | 0. |
| 15 | 0. | 0. | 0. | 0. | 15. | 35. | 29. | 31. | 34. | 50. | 31. | 27. | 30. | 19. | 14. | 22. | 18. | 18. | 18. | 19. | 12. | 8. | 3. | 10. | 0. |
| 14 | 0. | 0. | 0. | 0. | 0. | 23. | 15. | 25. | 37. | 45. | 50. | 48. | 43. | 39. | 29. | 23. | 16. | 22. | 17. | 14. | 9. | 0. | 1. | 4. | 0. |
| 13 | 0. | 0. | 0. | 0. | 0. | 4. | 17. | 17. | 39. | 40. | 45. | 38. | 35. | 32. | 26. | 27. | 18. | 20. | 14. | 18. | 18. | 16. | 0. | 0. | 0. |
| 12 | 0. | 0. | 0. | 0. | 0. | 0. | 26. | 27. | 36. | 37. | 26. | 26. | 27. | 31. | 31. | 30. | 25. | 16. | 15. | 19. | 17. | 16. | 13. | 4. | 7. |
| 11 | 0. | 0. | 0. | 0. | 0. | 0. | 12. | 35. | 32. | 31. | 26. | 22. | 26. | 34. | 31. | 28. | 30. | 17. | 16. | 22. | 15. | 13. | 14. | 9. | 11. |
| 10 | 0. | 0. | 0. | 0. | 0. | 0. | 5. | 27. | 22. | 21. | 21. | 11. | 18. | 25. | 33. | 30. | 27. | 21. | 21. | 26. | 23. | 23. | 19. | 10. | 4. |
| 9 | 0. | 0. | 0. | 0. | 0. | 0. | 1. | 32. | 24. | 23. | 20. | 12. | 27. | 20. | 19. | 19. | 25. | 33. | 29. | 37. | 24. | 21. | 20. | 21. | 6. |
| 8 | 0. | 0. | 0. | 0. | 0. | 0. | 1. | 9. | 22. | 20. | 14. | 15. | 26. | 44. | 35. | 26. | 27. | 30. | 28. | 30. | 29. | 33. | 13. | 19. | 12. |
| 7 | 0. | 0. | 0. | 0. | 0. | 0. | 7. | 7. | 2. | 11. | 14. | 10. | 6. | 9. | 22. | 20. | 13. | 16. | 19. | 27. | 30. | 35. | 47. | 30. | 12. |
| 6 | 0. | 0. | 0. | 0. | 0. | 0. | 7. | 10. | 13. | 31. | 12. | 0. | 0. | 0. | 0. | 3. | 13. | 21. | 19. | 22. | 20. | 34. | 15. | 5. | 2. |
| 5 | 0. | 0. | 0. | 0. | 0. | 0. | 1. | 1. | 5. | 3. | 1. | 0. | 0. | 0. | 0. | 0. | 6. | 21. | 20. | 25. | 13. | 12. | 8. | 2. | 7. |
| 4 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 7. | 20. | 20. | 2. | 9. | 10. | 1. | 2. |
| 3 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 5. | 19. | 18. | 20. | 10. | 2. | 0. |
| 2 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 10. | 17. | 5. | 0. | 0. |
| 1 | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. | 1. | 2. | 0. | 0. |

TOTAL POPULATION = 8139.2 THOUSAND PERSONS

FIGURE A2.10

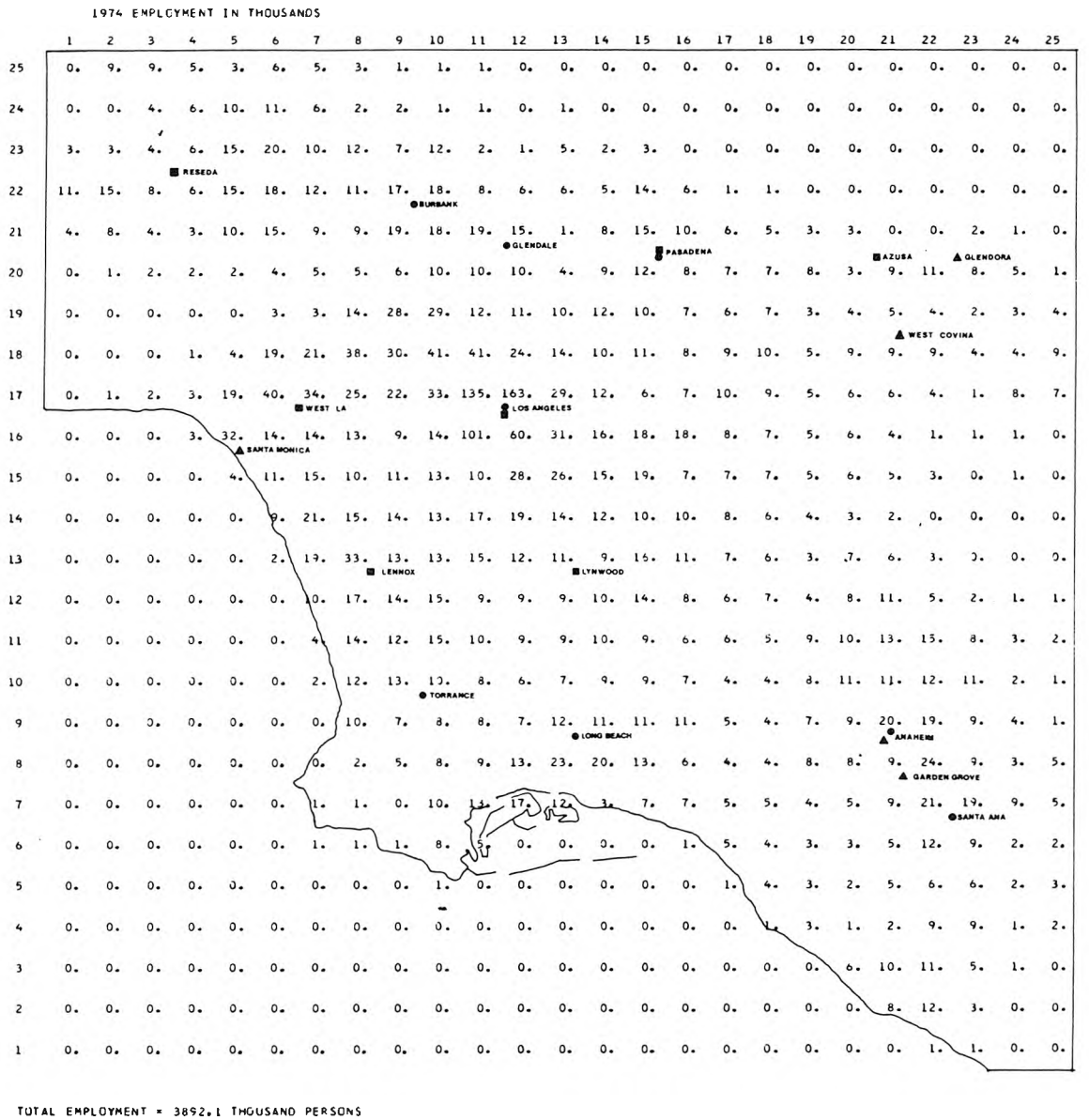

1974 EMPLOYMENT IN THOUSANDS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
25 0. 9. 9. 5. 3. 6. 5. 3. 1. 1. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
24 0. 0. 4. 6. 10. 11. 6. 2. 2. 1. 1. 0. 1. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
23 3. 3. 4. 6. 15. 20. 10. 12. 7. 12. 2. 1. 5. 2. 3. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
22 11. 15. 8. 6. 15. 18. 12. 11. 17. 18. 8. 6. 6. 5. 14. 6. 1. 1. 0. 0. 0. 0. 0. 0. 0.
21 4. 8. 4. 3. 10. 15. 9. 9. 19. 18. 19. 15. 1. 8. 15. 10. 6. 5. 3. 3. 0. 0. 2. 1. 0.
20 0. 1. 2. 2. 2. 4. 5. 5. 6. 10. 10. 10. 4. 9. 12. 8. 7. 7. 8. 3. 9. 11. 8. 5. 1.
19 0. 0. 0. 0. 0. 3. 3. 14. 28. 29. 12. 11. 10. 12. 10. 7. 6. 7. 3. 4. 5. 4. 2. 3. 4.
18 0. 0. 0. 1. 4. 19. 21. 38. 30. 41. 41. 24. 14. 10. 11. 8. 9. 10. 5. 9. 9. 9. 4. 4. 9.
17 0. 1. 2. 3. 19. 40. 34. 25. 22. 33. 135. 163. 29. 12. 6. 7. 10. 9. 5. 6. 6. 4. 1. 8. 7.
16 0. 0. 0. 3. 32. 14. 14. 13. 9. 14. 101. 60. 31. 16. 18. 18. 8. 7. 5. 6. 4. 1. 1. 1. 0.
15 0. 0. 0. 0. 4. 11. 15. 10. 11. 13. 10. 28. 26. 15. 19. 7. 7. 7. 5. 6. 5. 3. 0. 1. 0.
14 0. 0. 0. 0. 0. 9. 21. 15. 14. 13. 17. 19. 14. 12. 10. 10. 8. 6. 4. 3. 2. 0. 0. 0. 0.
13 0. 0. 0. 0. 0. 2. 19. 33. 13. 13. 15. 12. 11. 9. 16. 11. 7. 6. 3. 7. 6. 3. 0. 0. 0.
12 0. 0. 0. 0. 0. 0. 10. 17. 14. 15. 9. 9. 9. 10. 14. 8. 6. 7. 4. 8. 11. 5. 2. 1. 1.
11 0. 0. 0. 0. 0. 0. 4. 14. 12. 15. 10. 9. 9. 10. 9. 6. 6. 5. 9. 10. 13. 15. 8. 3. 2.
10 0. 0. 0. 0. 0. 0. 2. 12. 13. 13. 8. 6. 7. 9. 9. 7. 4. 4. 8. 11. 11. 12. 11. 2. 1.
9 0. 0. 0. 0. 0. 0. 0. 10. 7. 8. 8. 7. 12. 11. 11. 11. 5. 4. 7. 9. 20. 19. 9. 4. 1.
8 0. 0. 0. 0. 0. 0. 0. 2. 5. 8. 9. 13. 23. 20. 13. 6. 4. 4. 8. 8. 9. 24. 9. 3. 5.
7 0. 0. 0. 0. 0. 0. 1. 1. 0. 10. 14. 17. 12. 3. 7. 7. 5. 5. 4. 5. 9. 21. 19. 9. 5.
6 0. 0. 0. 0. 0. 0. 1. 1. 1. 8. 5. 0. 0. 0. 0. 1. 5. 4. 3. 3. 5. 12. 9. 2. 2.
5 0. 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0. 0. 0. 0. 1. 4. 3. 2. 5. 6. 6. 2. 3.
4 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 1. 3. 1. 2. 9. 9. 1. 2.
3 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 6. 10. 11. 5. 1. 0.
2 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 8. 12. 3. 0. 0.
1 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 1. 1. 0. 0.
RESEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
TOTAL EMPLOYMENT = 3892.1 THOUSAND PERSONS

FIGURE A2.11

SOX EMISSIONS FROM INDUSTRIAL, COMMERCIAL AND RESIDENTIAL FUEL BURNING (SHADED)
VS. TOTAL SOX EMISSIONS WITHIN THE 50 BY 50 MILE SQUARE

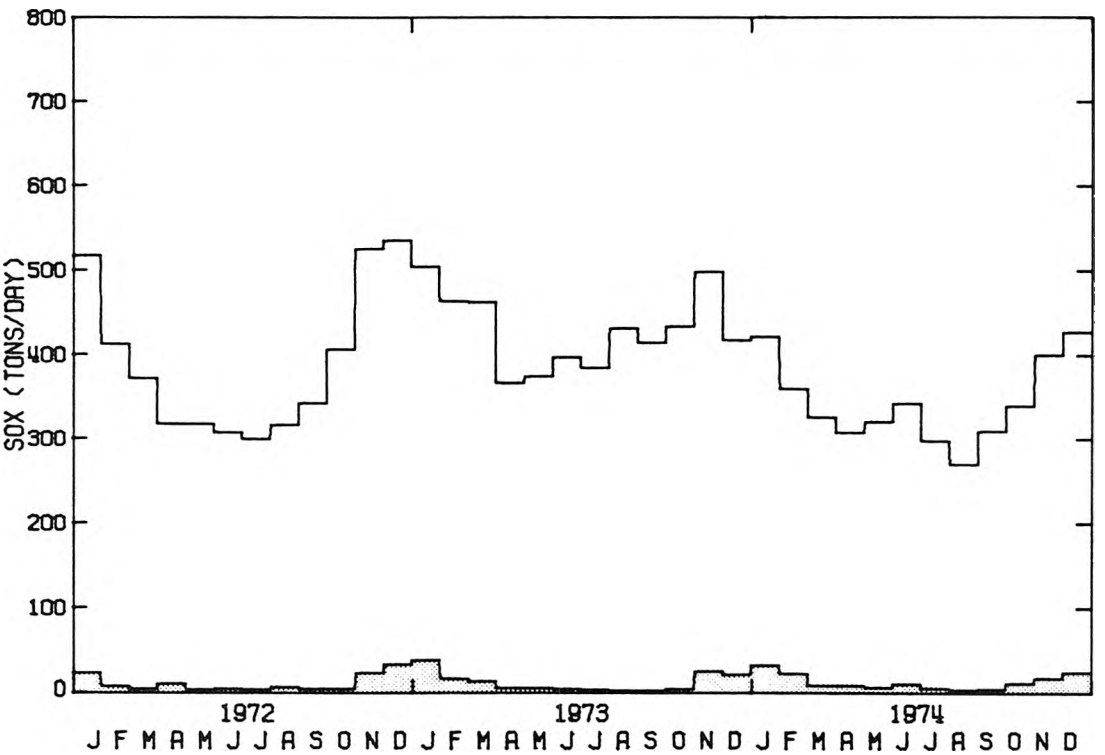



FIGURE A2.12

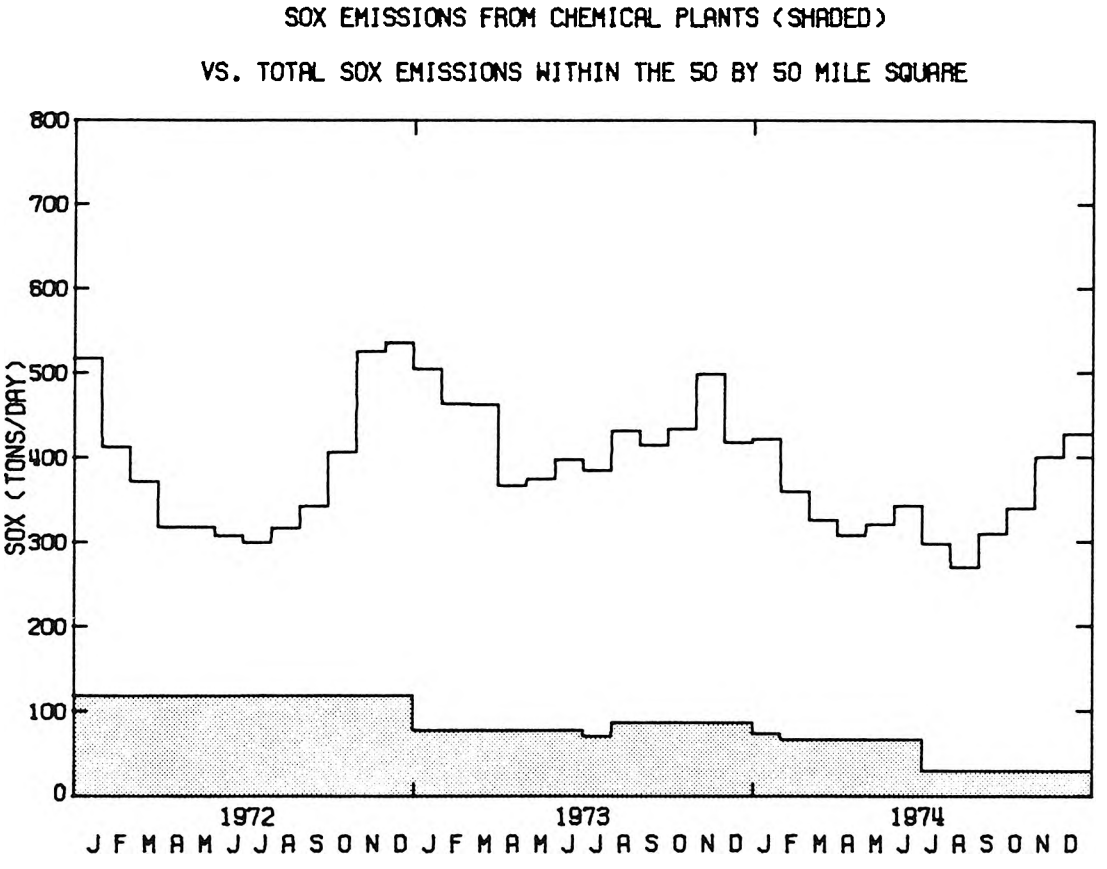

SOX EMISSIONS FROM CHEMICAL PLANTS (SHADED)
VS. TOTAL SOX EMISSIONS WITHIN THE 50 BY 50 MILE SQUARE
SOX (TONS/DAY)
800
700
600
500
400
300
200
100
0
1972
1973
1974
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

FIGURE A2.13

hydrogen sulfide was left in refinery fuel gases or incinerated to form $SO_2$ and released to the atmosphere from refinery flare stacks, the resulting $SO_x$ emissions would have totaled nearly 2000 tons per day (as $SO_2$) in that year. In that event, total $SO_x$ emissions within the 50 by 50 mile grid would have been about five times higher than was the case during the year 1973.

In order to prevent this sulfur release to the atmosphere, hydrogen sulfide is stripped from refinery gas streams by amine absorption units. After being concentrated, most of the $H_2S$ is then ducted to Claus sulfur recovery plants. Sulfuric acid manufacturing plants are also used to process some of this hydrogen sulfide waste gas.

The Claus sulfur recovery plants operated in the Los Angeles basin prior to 1973 were about 90% to 95% efficient at converting $H_2S$ to elemental sulfur (Hunter and Helgeson, 1976). As refinery capacity and complexity increased over the years, the quantity of $H_2S$ generated increased. This lead to a corresponding growth in atmospheric emissions from sulfur recovery plant exhaust. By the start of 1971, sulfur recovery and sulfuric acid plant emissions totaled 116 tons of $SO_2$ per day (almost half of the total $SO_x$ emissions in Los Angeles County at that time (Lemke, et al., 1971).

To limit sulfur recovery plant emissions further, the LAAPCD adopted emission control regulations which in effect required that Claus plants be equipped with tail gas clean-up units. The impact of this emission control policy change was not felt simultaneously

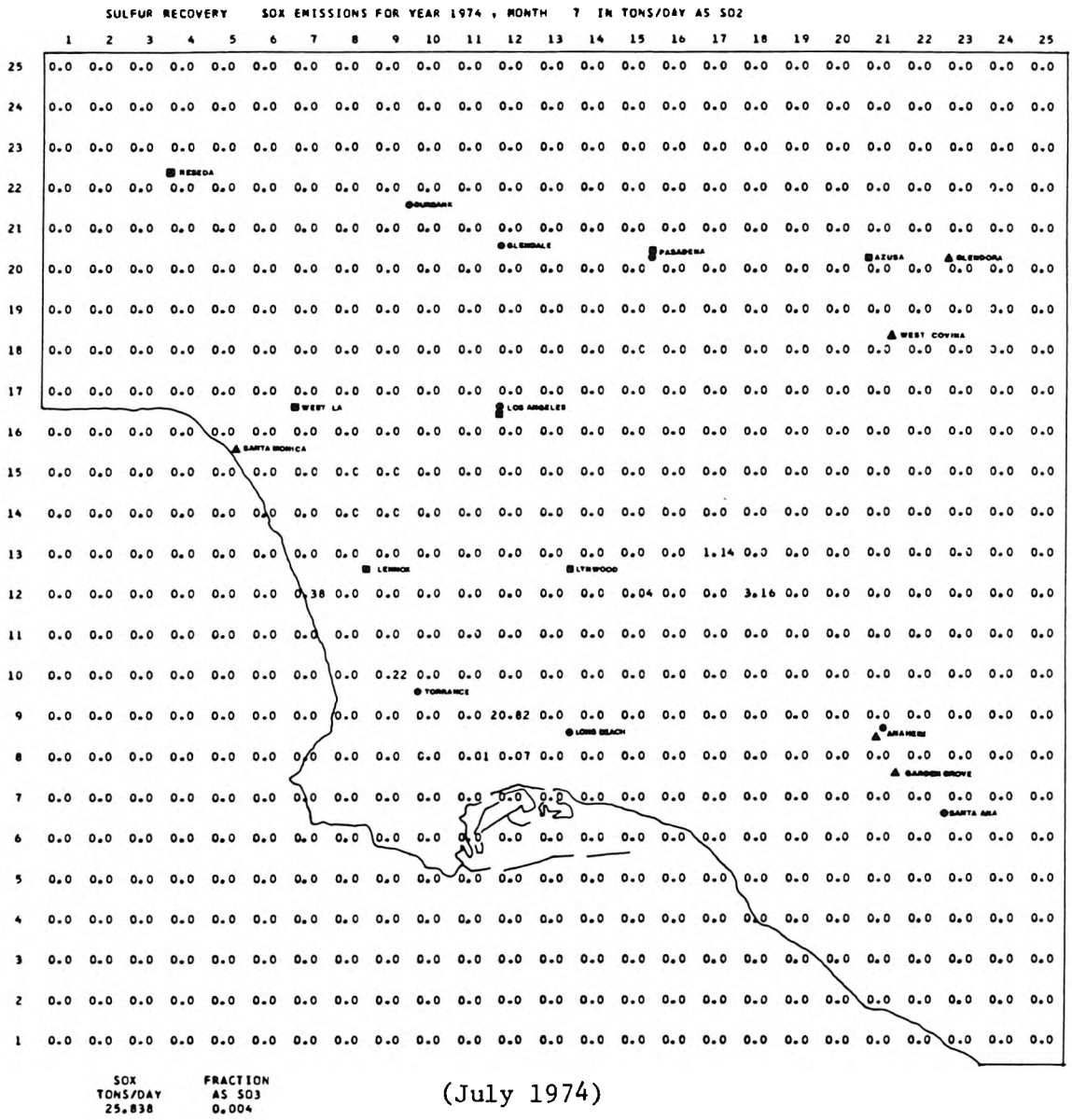
at all refineries. The first tail gas units went on-line at the beginning of 1973. Throughout the years 1973 and 1974 sulfur recovery plant tail gas units at additional refineries began operation. Total $SO_x$ emissions from the phased installation of tail gas clean-up systems appear as shown in Tables A2.14 through A2.16 in the summary to this appendix.

Sulfur balances on the basin's oil refineries and chemical plants have been computed by APCD engineers for the years 1973 and 1974 (Southern California Air Pollution Control District, 1976a). These sulfur balances include atmospheric emissions estimates for each major type of chemical or refinery process at each facility. The mass balance approach provides reasonable assurance that atmospheric emissions estimates are consistent with total refinery sulfur intake on a year-round basis. In all but two cases, individual source estimates used to compile the time history of sulfur recovery plant emissions reported in our inventory were based on the APCD's sulfur balances entitled "Sulfur Recovery and Sulfuric Acid Plant Operations -- Los Angeles County", 1973 and 1974 editions. Discussions with APCD engineers were used to estimate the date of startup of new equipment items, and the magnitude of emissions before and after the change in equipment. In general, January 1973 emissions derived from the APCD chemical plant sulfur balances were carried backward to represent source emissions during 1972. An exception to this procedure had to be made in the case of 1972 $SO_x$ emissions from the Allied Chemical/Standard Oil sulfur recovery complex. At the close of 1972, the old sulfur plant in question was

abandoned. Historic files on this source have been discarded by the APCD. $SO_x$ emissions for the abandoned facility were thus estimated on the basis of 1973 annual average sulfur throughput at the new Standard Oil sulfur plant, combined with Hunter and Helgeson's (1976) uncontrolled Claus plant source test result of 333 pounds of $SO_x$ per ton of sulfur processed. Hunter and Helgeson's source test data were also used to compute emissions from the new ARCO sulfur recovery plant prior to completion of its tail gas clean-up system.

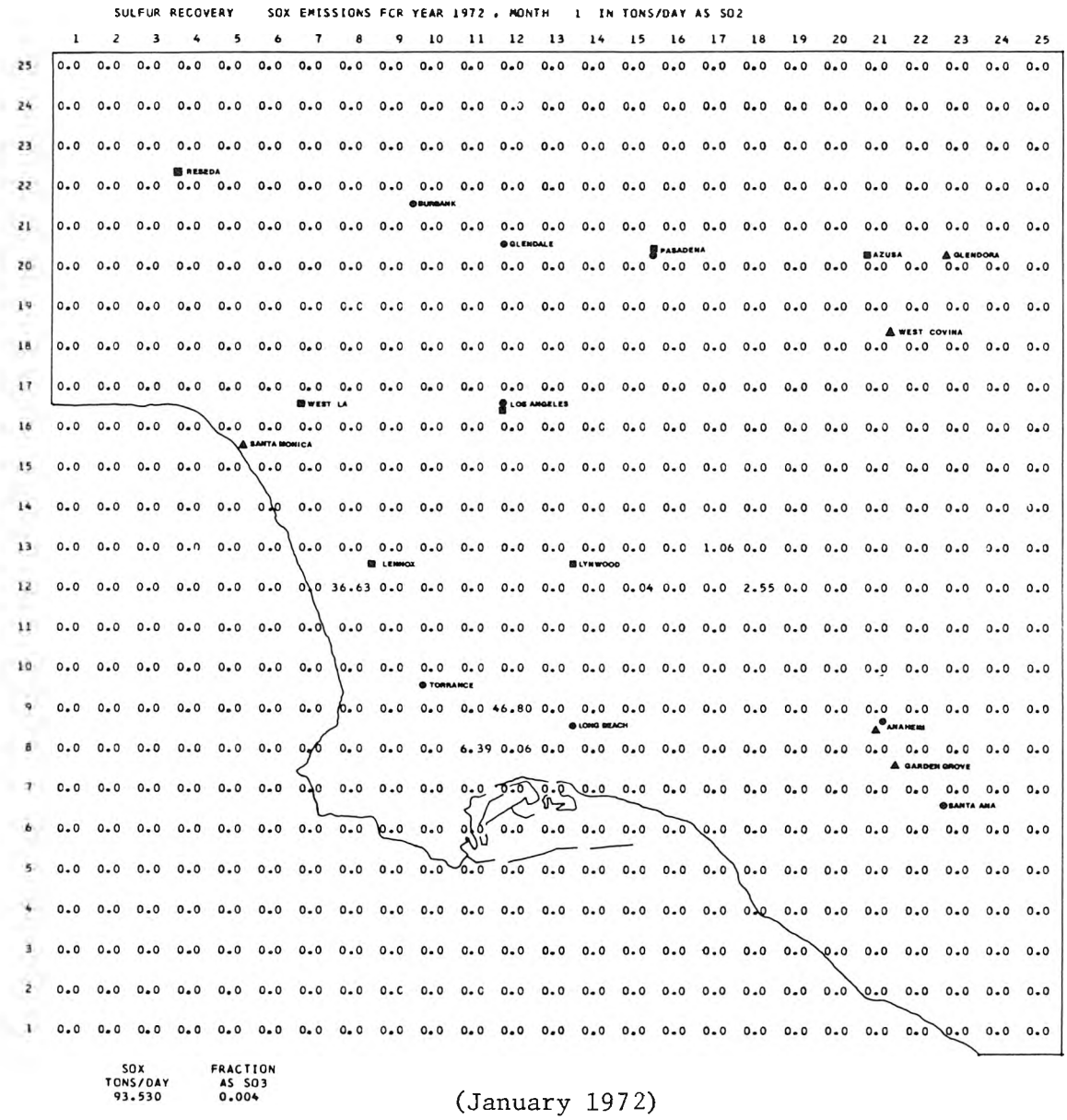
By December 1974, $SO_x$ emissions from Claus sulfur recovery plants had been reduced to 25.8 tons per day from a January 1972 level of about 93.5 tons per day. At least two refineries were still experiencing operating trouble with their new tail gas units at the end of 1974. Once those sources are corrected, $SO_x$ emissions from sulfur recovery plants should drop to about 3 tons per day.

The spatial distribution of $SO_x$ emissions from sulfur recovery plants for mid-1974 is shown in Figure A2.14, as compared to an estimate for January 1972 in Figure A2.15. A substantial change in the spatial distribution of emissions occurred during our study period. Most of these spatial changes in emission strength are due to imposition of emission controls. In addition, certain refineries whose effluent was once processed by outside chemical contractors decided to build their own sulfur recovery plants at another location.




(July 1974)

FIGURE A2.14



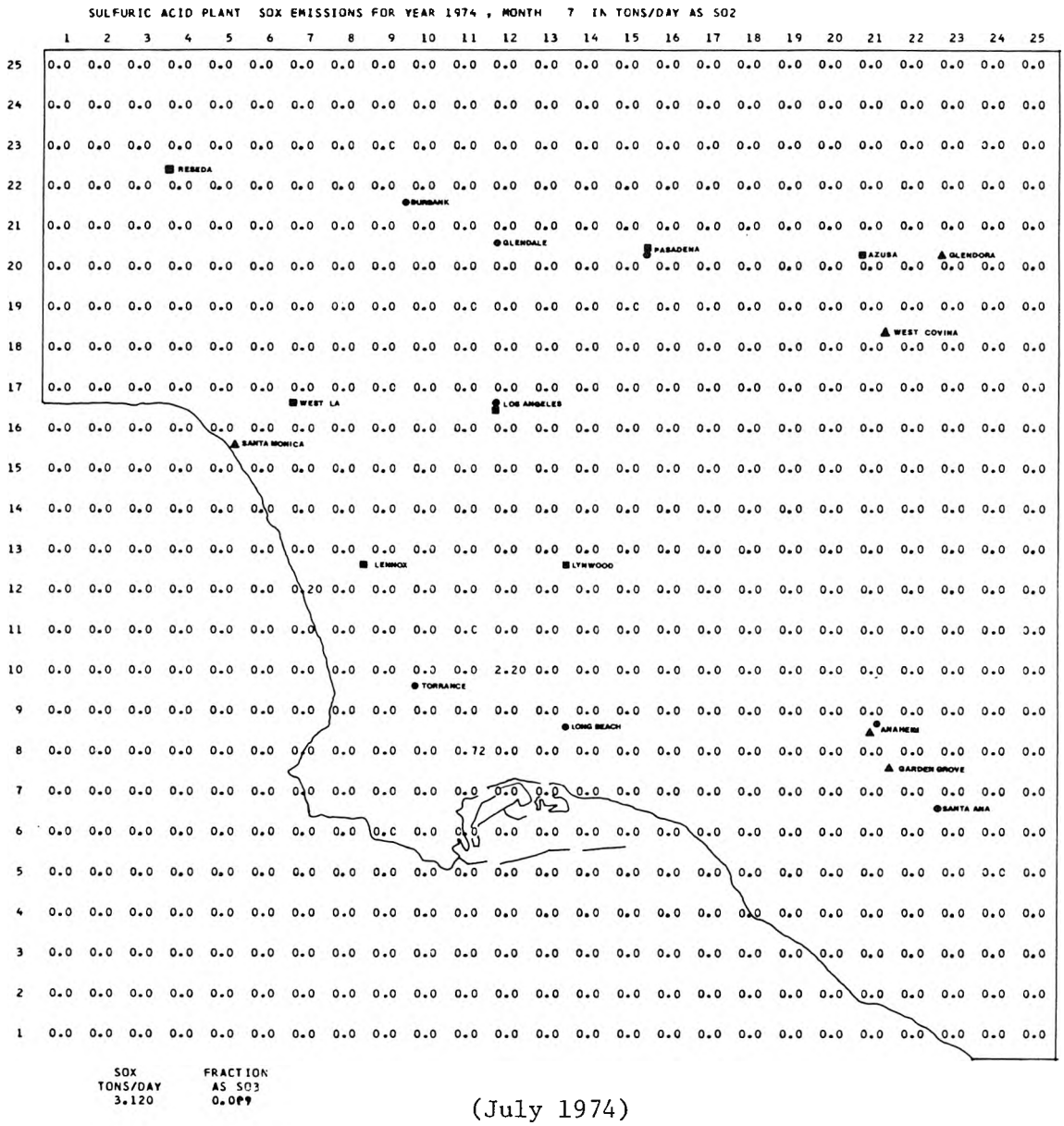

(January 1972)

FIGURE A2.15

A2.3.2 Sulfuric Acid Plants

Sulfuric acid production is the second type of industrial process used to recover sulfur from refinery wastes. Five contact process acid plants are operated at three plant sites in Los Angeles County. These plants consumed a variety of feed stocks. During the year 1973, for example, sulfuric acid production consumed the equivalent of 480 tons per day of elemental sulfur. About 38 percent of this sulfur input came from reprocessing acid sludge, 44 percent from burning elemental sulfur, and 18 percent from burning hydrogen sulfide (Southern California Air Pollution Control District, 1976a).

During the period of this emission inventory, sulfuric acid plant emissions were substantially reduced through the installation of additional control equipment. Sulfur oxides emissions of at least 25 tons per day in 1971 (Lemke, et al, 1971) were reduced to 3.12 tons per day during 1974 (Southern California Air Pollution Control District, 1976a). The spatial distribution of sulfuric acid plant emissions for a summer month in 1974 is given in Figure A2.16. The previously mentioned APCD chemical plant sulfur balances were the basis for all emissions estimates made, except for emissions from the Allied Chemical/Standard Oil complex acid plant during the year 1972. Pre-1973 emissions at that abandoned plant were estimated by taking January 1973 emissions from acid plants not connected with the Standard Oil refinery and subtracting those emissions from Los Angeles County total acid plant $SO_x$ emissions of 25 tons per day in 1971 as reported by Lemke, et al. (1971).




(July 1974)

FIGURE A2.16

### A2.3.3 Miscellaneous Chemical Operations

About 0.09 tons per day of $SO_x$ are emitted from other industrial operations employing chemicals. These include detergent manufacturing and one glass bottle factory which finishes some of their products by exposing them to sulfur dioxide gas.

## A2.4 Emissions from Petroleum Refining and Production

Total inventoried emissions from petroleum refinery processes and oil field operations are shown in time series in Figure A2.17, along with total $SO_x$ emissions within the 50 by 50 mile square grid. The geographic distribution of emission sources is given in Figure A2.18 for a typical day in 1973. For the purpose of this discussion, the source classes used to represent $SO_x$ emissions from petroleum refining and production are:

- Fluid Catalytic Crackers
- Other Refinery Process Equipment
- Oil Field Production Operations

### A2.4.1 Fluid Catalytic Crackers

The vast bulk of refinery industrial process $SO_x$ emissions in the South Coast Air Basin originate from eight fluid catalytic cracking units (FCCU) at refineries within the 50 by 50 mile grid. The purpose of these devices is to break large hydrocarbon molecules contained in gas oils down into lighter molecules suitable for blending into the gasoline pool. The heavy hydrocarbons introduced into the FCCUs are accompanied by bound sulfur which tends to accumulate in a coke layer formed over the surface of the cracker's

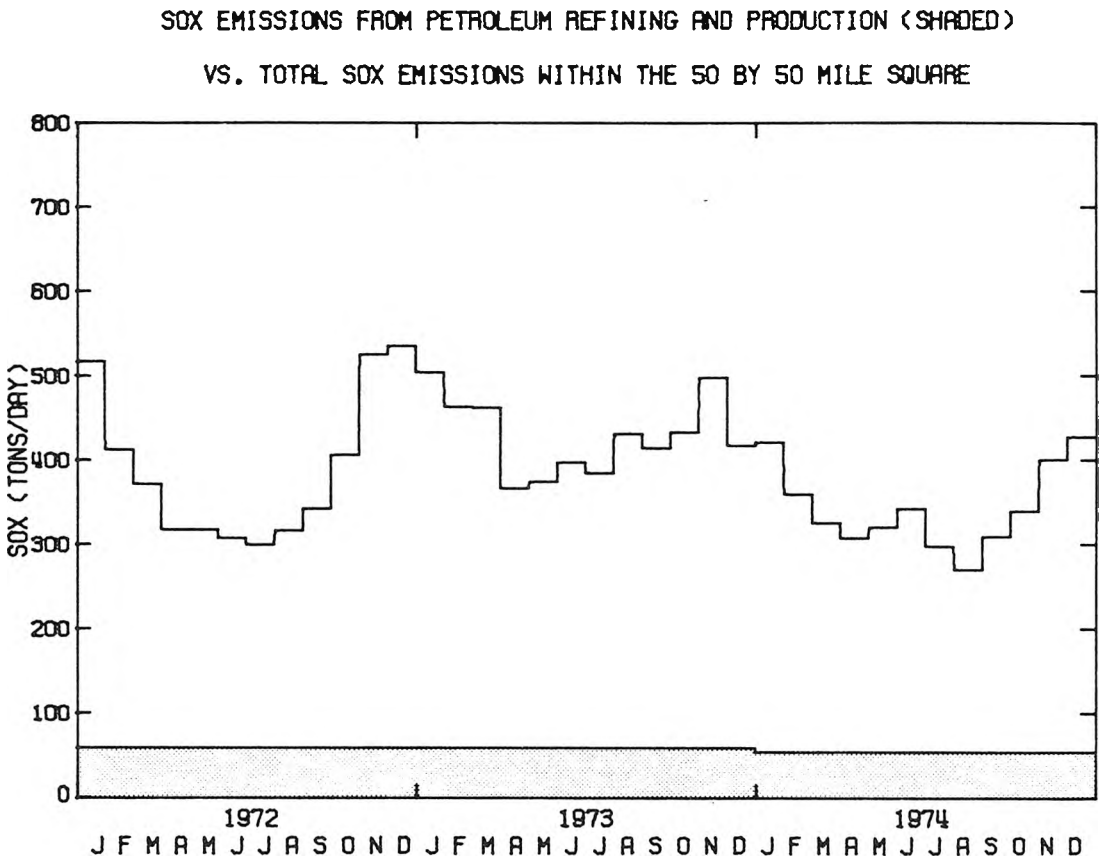

SOX EMISSIONS FROM PETROLEUM REFINING AND PRODUCTION (SHADED)
VS. TOTAL SOX EMISSIONS WITHIN THE 50 BY 50 MILE SQUARE
SOX (TONS/DAY)
800
700
600
500
400
300
200
100
0
1972
1973
1974
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

FIGURE A2.17

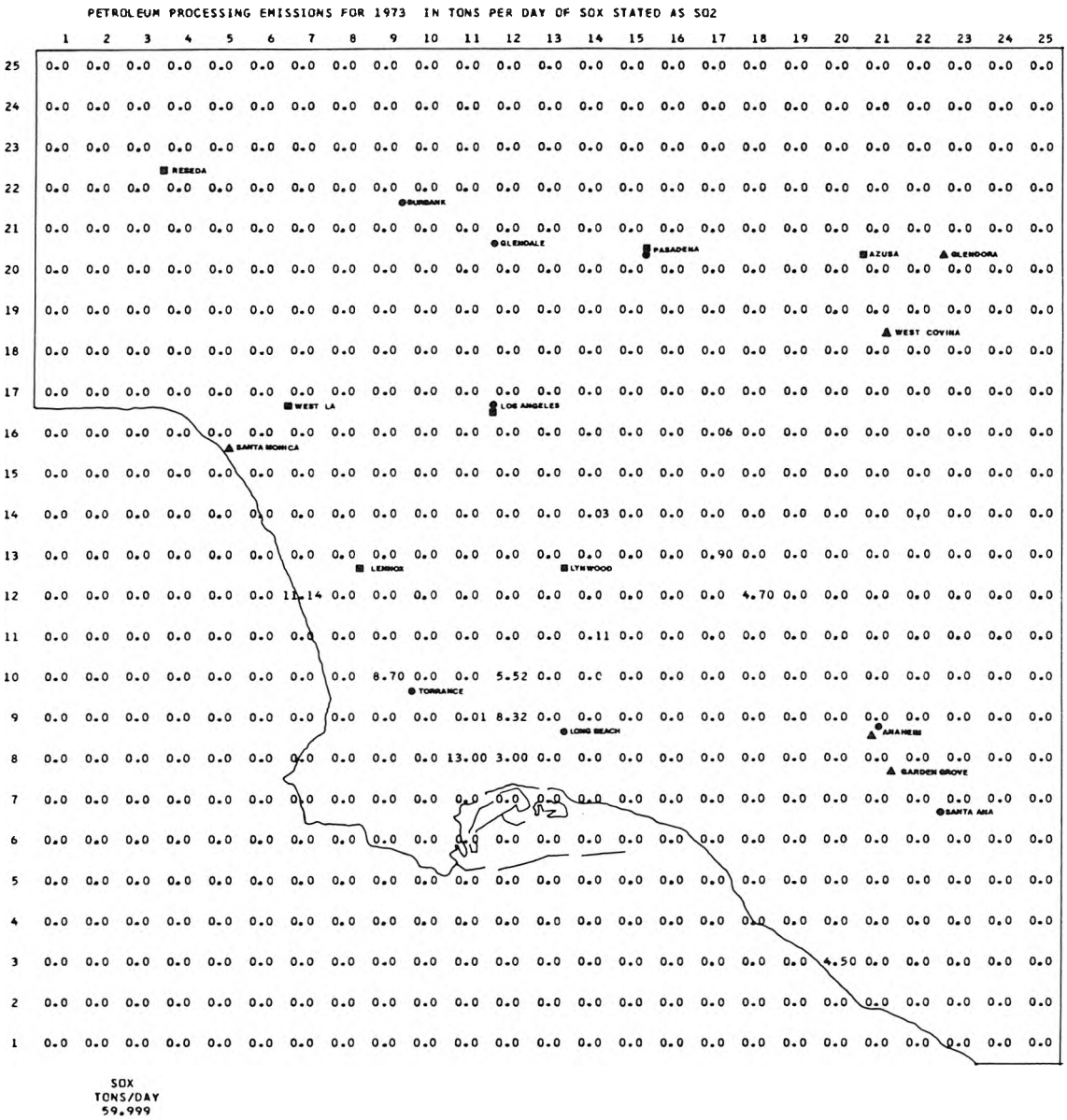

PETROLEUM PROCESSING EMISSIONS FOR 1973 IN TONS PER DAY OF SOX STATED AS SO2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
25 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
24 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
23 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
22 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
21 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
20 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
19 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
18 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
17 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
16 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.06 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
15 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
14 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.03 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
13 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.90 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
12 0.0 0.0 0.0 0.0 0.0 0.0 11.14 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 4.70 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
11 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.11 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
10 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 8.70 0.0 0.0 5.52 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
9 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.01 8.32 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 13.00 3.00 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
7 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
6 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
5 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
4 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
3 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 4.50 0.0 0.0 0.0 0.0 0.0
2 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
RESEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
SOX
TONS/DAY
59.999

FIGURE A2.18

catalyst charge. In order to regenerate the catalyst material, this coke layer is burned off, releasing the sulfur to the atmosphere.

Figure A2.19 shows the geographic distribution of FCCU emissions for a typical day during the year 1973. These data are taken from the Southern California APCD's "Sulfur Balance - Los Angeles County Refineries", 1973 and 1974 editions (Southern California Air Pollution Control District, 1976a). Recent source tests reported by Hunter and Helgeson (1976) placed average 1974 FCCU emissions at 45.56 tons per day, which compares very favorably to the APCD's value of 45.48 tons per day for that year. The APCD's average daily values will be used for each day of 1973 and 1974, and the 1973 data will be assumed to represent 1972 as well.

A2.4.2 Other Refinery Process Equipment

In addition to the 45.5 tons per day of $SO_x$ emitted from fluid catalytic cracking in 1974, there were smaller but non-negligible $SO_x$ emissions from at least 37 pieces of other refinery process equipment. Emissions from these miscellaneous equipment items averaged 3.43 tons per day in 1973 and 4.17 tons per day in 1974. The most significant $SO_x$ sources involved include delayed coker blow-down units, and sour water strippers which are listed separately in Tables A2.14 through A2.16 in the summary to this appendix.

Emissions from sour water strippers, caustic regeneration, and $SO_2$ treating operations were taken from the APCD sulfur balance summaries. Additional equipment items not specified in the sulfur balance but identified in the APCD permit file were included in the

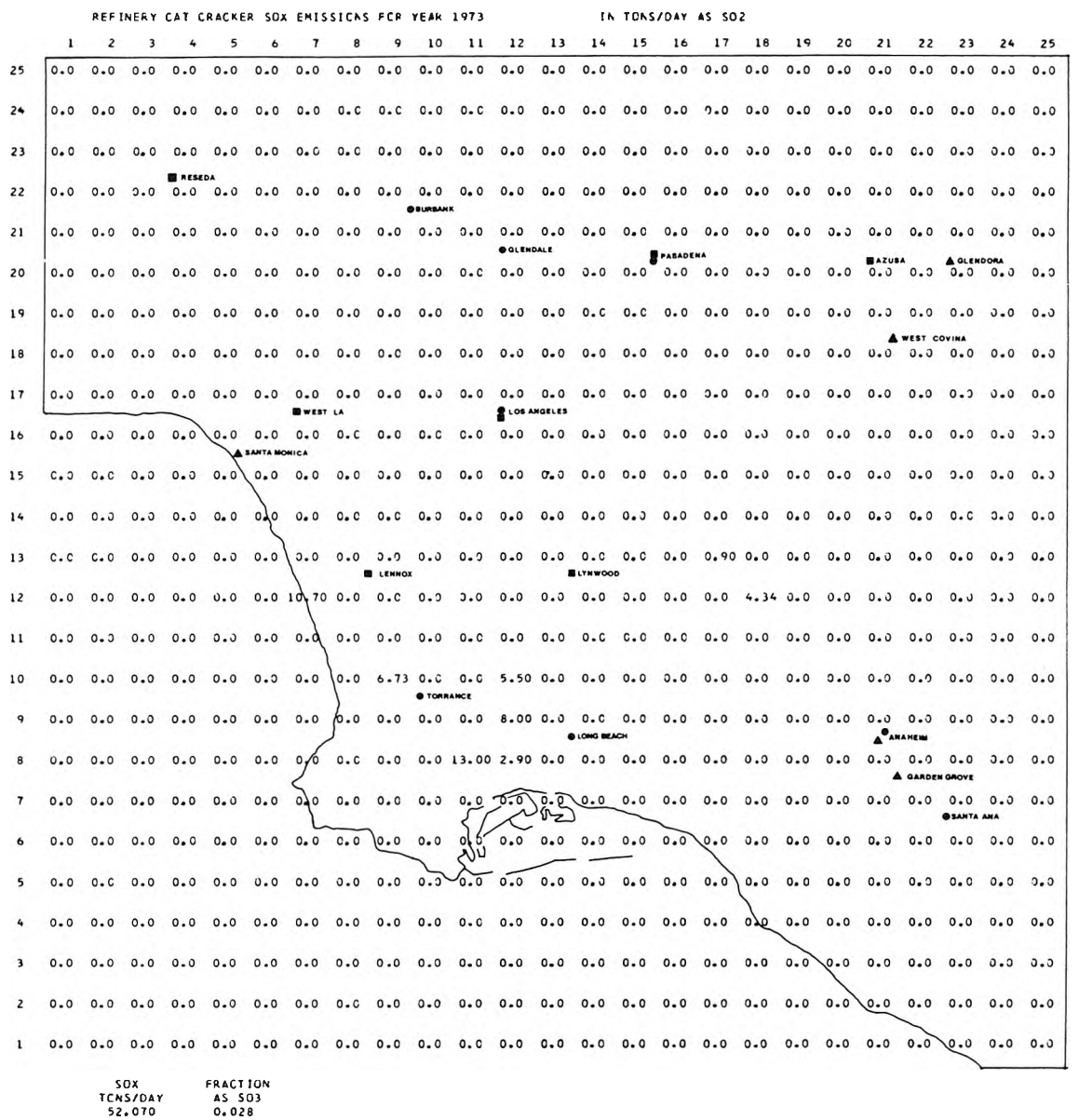

REFINERY CAT CRACKER SOX EMISSIONS FOR YEAR 1973
IN TONS/DAY AS SO2
RESEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
SOX TONS/DAY 52.070
FRACTION AS SO3 0.028

FIGURE A2.19

inventory at their permit file $SO_x$ emission rate. This later group of equipment included emissions from delayed coker blow-down units at two refineries. Additional refineries in the Los Angeles area have coking facilities (see Cantrell, 1973). There may be emissions from other blow-down units of which we are not aware, unless these units are connected directly to sulfur recovery plants at all times during the coking cycle.

### A2.4.3 Oil Field Production Operations

Fire flooding used to stimulate oil production at one Newport Beach area oil field results in generation of $H_2S$-containing exhaust gases. These sour gases are subsequently burned in a group of fume incinerators as a means of preventing the $H_2S$ from reaching the atmosphere (Hunter and Helgeson, 1976). Historic $SO_x$ emission data for these sources provided by the Southern California APCD-Southern Zone will be used in this study as indicated in Table A2.9. The 5.17 tons per day value given in that table for 1974 compares fairly closely with Hunter and Helgeson's estimated 1974 emissions from these sources of 5.4 tons per day of $SO_x$.

## A2.5 Miscellaneous Stationary Sources

This miscellaneous stationary source category includes $SO_x$ emissions from materials fabrication processes and from waste disposal. The source classes used to represent miscellaneous stationary sources are:

- Petroleum Coke Calcining Kilns
- Glass Furnaces

TABLE A2.9

$SO_x$ Emissions from Oil Field Production Activities in the Vicinity of Newport Beach

| Year | Oil Field Operation $SO_x$ Emissions (tons/day) |
|---|---|
| 1972 | 4.0 |
| 1973 | 4.5 |
| 1974 | 5.17 |

Reference: Records of the Southern California APCD - Southern Zone (Kaye, 1976).

- Metals Processing Plants
- Mineral Processing Plants
- Sewage Treatment Plants
- Miscellaneous Industries
- Industrial/Commercial/Institutional Incinerators

In the first four of these industrial classes, sulfur contained in raw materials is released when materials are heated to high temperatures during a manufacturing process. Emissions from sewage treatment plants and incinerators are the by-products of a waste disposal process.

The magnitude of miscellaneous process emissions is thought to have been fairly constant over the three years of interest, as shown in Figure A2.20. The annual average spatial distribution of these industrial process emissions is shown in Figure A2.21 for the year 1973 for sources located within the 50 by 50 mile grid. There are, however, a number of major off-grid metals and minerals processing $SO_x$ emissions sources, as can be seen by reviewing emissions data for off-grid sources given in Tables A2.14 through A2.16 in the summary to this appendix.

### A2.5.1 Petroleum Coke Calcining Kilns

Coke calcining kilns are by far the largest source of $SO_x$ emissions from miscellaneous industrial processes within the 50 by 50 mile grid. Petroleum coke produced at local oil refineries is calcined in five large rotary kilns in the Los Angeles harbor area. The input coke to these kilns is a solid made from the highest

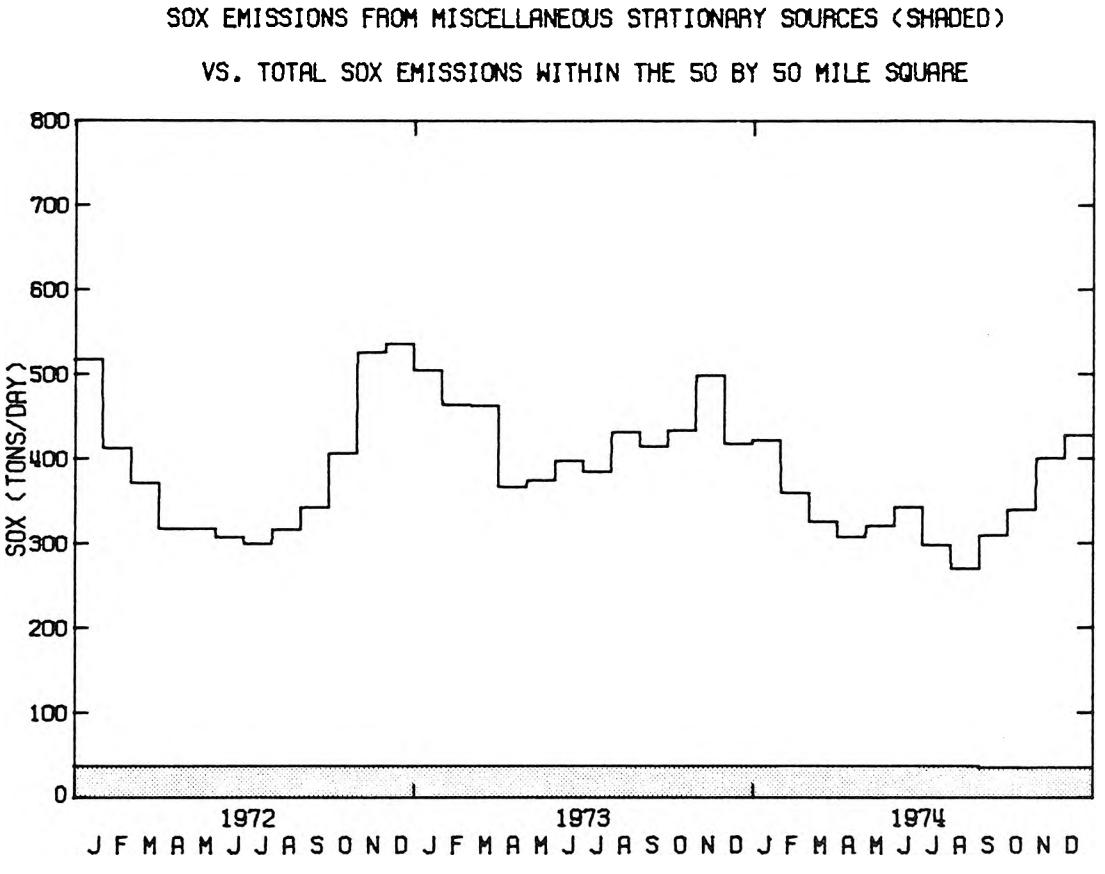

SOX EMISSIONS FROM MISCELLANEOUS STATIONARY SOURCES (SHADED)
VS. TOTAL SOX EMISSIONS WITHIN THE 50 BY 50 MILE SQUARE
SOX (TONS/DAY)
800
700
600
500
400
300
200
100
0
1972
1973
1974
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

FIGURE A2.20

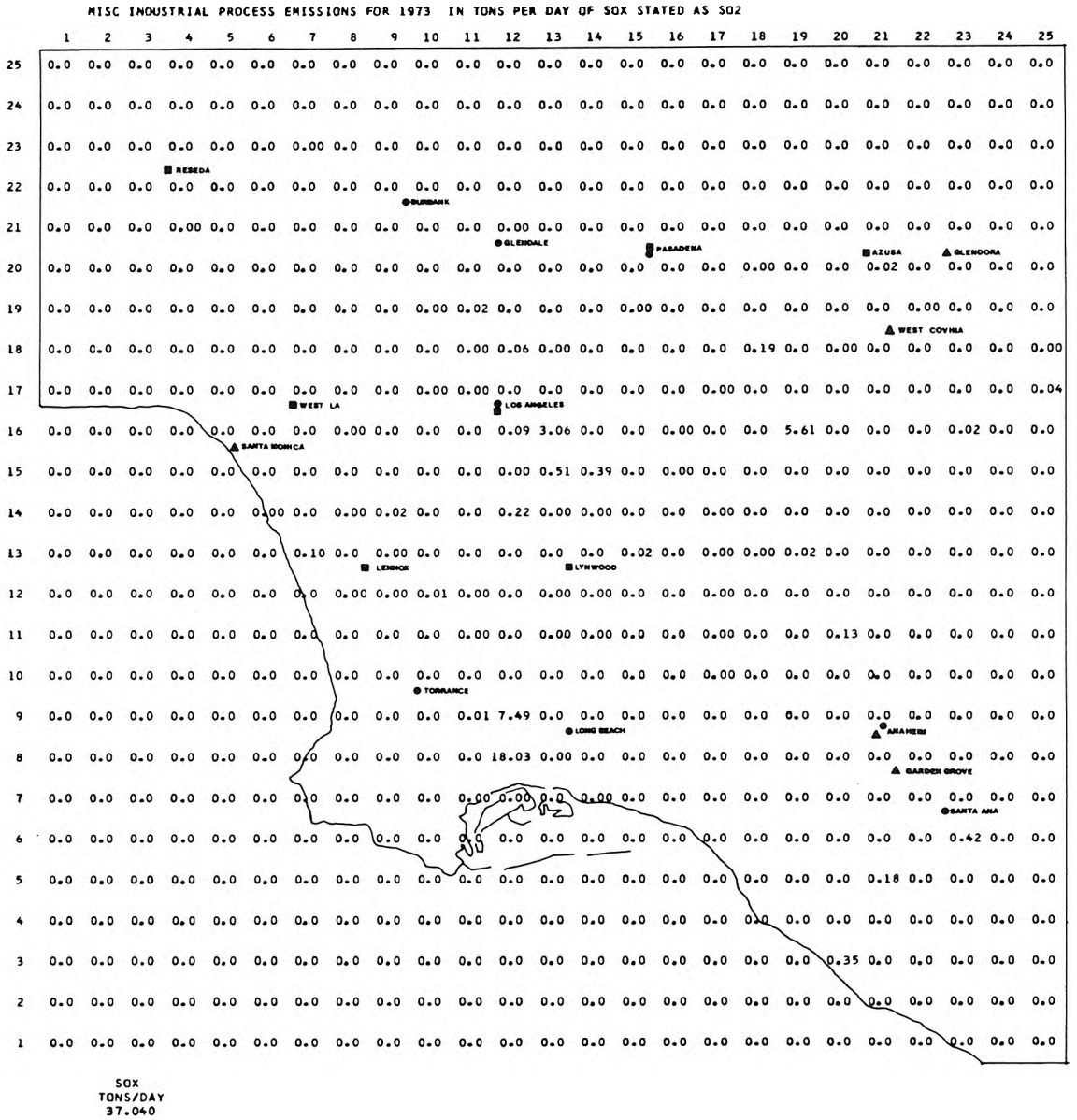

MISC INDUSTRIAL PROCESS EMISSIONS FOR 1973 IN TONS PER DAY OF SOX STATED AS SO2
RESEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
SOX
TONS/DAY
37.040

FIGURE A2.21

sulfur portions of the crude oil arriving at the refineries. As the coke is heated in these kilns, coke dust becomes entrained in the exhaust gases and is burned releasing bound sulfur as $SO_2$ or $SO_3$. $SO_x$ emissions from these sources were inventoried at 25.5 tons per day for each year based on data presented by Hunter and Helgeson (1976). Due to their extremely high exhaust gas temperatures, coke calcining kilns have the highest fraction $SO_3$ in their exhaust and the highest average effective stack height of all major sources in the air basin.

### A2.5.2 Glass Furnaces

There are 26 glass furnaces at 13 locations itemized within this emissions inventory. Twenty-two of these furnaces are located within the 50 by 50 mile grid. Emissions from all but two of these furnaces were based on APCD source tests or permit file emissions estimates. Emissions from furnaces at Glass Containers Corp. were estimated from KVB source test data (Hunter and Helgeson, 1976). Source tests selected in determining emission rates were all conducted while the furnaces were heated with either natural gas or electricity; any emissions from fuel oil combustion were inventoried in the fuel burning section of this report. Sulfur oxides emissions given here derive from fluxes ($Na_2SO_4$ or $BaSO_4$) used in the glass batch or from coloring agents (for example, iron pyrites) added to the glass. Estimates made largely from APCD data indicate that all glass furnaces together emitted about 2.0 tons per day of $SO_x$ in recent years within the 50 by 50 mile square, and 2.23 tons per day

within the entire air basin. Basin-wide glass furnace emissions of 2.15 tons per day were estimated by Hunter and Helgeson (1976). While agreement between these two data bases seems close, the APCD staff cautions us that glass furnace emissions are very erratic and change widely from one source test to the next, even under seemingly identical furnace operating conditions (Simon, 1976).

A2.5.3 Metals Processing Plants

Metals processing plant emissions totaled about 8.76 tons per day within the 50 by 50 mile grid during 1973. These sources include secondary lead smelters, brass furnaces and ferrous metals melting furnaces. Off-grid metal processing emissions are much larger, however, because of the need to include emissions from Kaiser Steel located in Fontana.

Secondary lead smelters are engaged in recovering lead from the plates of discarded automobile batteries. These batteries contained sulfuric acid. Sulfur compounds retained on the battery plates are emitted to the atmosphere when the plates are remelted. This inventory contains estimates for five secondary lead melting furnaces with combined $SO_x$ emission rates averaging 8.67 tons per day during the years of interest.

Permit file emissions estimates for the five large lead furnaces were discarded, and emissions estimates were made from APCD source test data by an APCD engineer assigned to one of the sources (Menkus, 1976). A number of small lead sweating furnaces and melting pots originally assigned significant emissions rates in the APCD permit

file were determined by discussion with APCD staff engineers to have negligible $SO_x$ emissions rates. These smaller devices were dropped from the inventory.

$SO_x$ emissions from other on-grid melting furnaces originate almost entirely from the fuel being burned to heat the furnaces. Fuel burning at on-grid steel mills has already been included in the industrial fuel burning inventory.

The principal off-grid metals processing plant is Kaiser Steel, located in Fontana in San Bernardino County. Emissions estimates for Kaiser Steel are available from the Southern California Air Pollution Control District (1976b), from Hunter and Helgeson (1976), and from the steel mill's staff (Smith, 1976). Discussions with Kaiser personnel indicate that this steel mill's $SO_x$ emissions are directly proportional to the percentage of full capacity at which the mill is being operated. Therefore, in this inventory we have used total plant emissions rates calculated from Kaiser steel mill average capacity utilization in each year applied to Hunter and Helgeson's emission inventory estimates for 1974. The relative split in emissions between process types will be taken in proportion to Hunter and Helgeson's itemization in Table A2.10.

It should be noted that most of this steel mill's $SO_x$ emissions result from fuel burning activities, including combustion of coke oven gas and blast furnace gas. These fuel burning emissions are itemized here because our spatially resolved industrial fuel burning survey did not extend beyond the borders of the 50 by 50 mile square.

TABLE A2.10

Estimation of $SO_x$ Emissions from Kaiser Steel Mill In Fontana, California

| Device | Number of Devices | $SO_x$ Emissions (tons per average day) (YEAR) 1974(b) | 1973(c) | 1972(c) |
|---|---|---|---|---|
| Coke Ovens | 7 | 6.93 | 7.54 | 6.40 |
| Steel Furnace (burning coke oven gas) | 13 | 12.60 | 13.71 | 11.63 |
| Sinter Machine | 2 | 4.37 | 4.75 | 4.04 |
| Open Hearth Furnaces | 8(a) | 5.33(a) | 5.80 | 4.92 |
| Blast Furnace | 4 | 1.12 | 1.22 | 1.03 |
| Boilers | 7 | 7.67 | 8.34 | 7.08 |
| TOTAL EMISSIONS | | 38.02(d) | 41.36 | 35.10 |

Notes:

(a) Estimated from Hunter and Helgeson (1976) after subtraction of four open hearth furnaces at U.S. Steel with FY74-75 $SO_x$ emissions of 0.14 tons/day (Southern California Air Pollution Control District, 1976b).

(b) From Hunter and Helgeson (1976).

(c) According to Kaiser staff (Smith, 1976), emissions are proportioned to utilization of mill capacity.

| Year | Mill Capacity Utilization |
|---|---|
| 1972 | 84% |
| 1973 | 99% |
| 1974 | 91% |

Therefore, Hunter and Helgeson's emissions estimates were scaled to preceeding years on the basis of changes in mill capacity utilization.

(d) The Southern California Air Pollution Control District (1976b) places FY74-75 Kaiser Steel emissions at 37.36 tons per day. However, emissions estimates provided by Kaiser staff (Smith, 1976) for 46 days in 1975 averaged 24.02 tons/day during a period when the mill operated at 75% of capacity. By that data set, full capacity emissions would be 32 tons/day. The reason for the emission estimate disagreement is not known.

### A2.5.4 Mineral Processing Plants

Excluding glass furnaces which were inventoried separately, there are no major mineral processing $SO_x$ emissions sources located within the 50 by 50 mile square grid. Two off-grid sources will be inventoried as shown in Table A2.11. Crestlite is engaged in manufacturing of lightweight aggregate, while the other source's line of work speaks for itself. There are several cement kilns located beyond the borders of the 50 by 50 mile square. Emissions inventories available from the Southern California Air Pollution Control District (1976b) and from Hunter and Helgeson (1976) indicate that virtually all of the $SO_x$ formed during fuel combustion is removed by the lime being formed in these cement kilns. Cement plant $SO_x$ emissions appear to be negligible and were dropped from this inventory in order to reduce the number of off-grid sources considered.

### A2.5.5 Miscellaneous Industrial Processes

There are 42 items of industrial process equipment within the 50 by 50 mile grid remaining in the APCD permit file with $SO_x$ emissions too small to have warranted a separate discussion of their mode of operation. Emissions from these sources totaled about 0.23 tons per day. With one exception, permit file emissions for such sources were accumulated to the grid system without further screening. One brake shoe debonder with fairly substantial permit file emissions was tested by Hunter and Helgeson (1976) and found to have negligible $SO_x$ emissions. This source was deleted from our files.

TABLE A2.11

Itemization of Non-Utility Off-Grid Sources Included Within the Air Quality Modeling Emission Inventory

| Stationary Source Type | Grid Square Location | | Emission Rate (tons/day $SO_x$) | | |
|---|---|---|---|---|---|
| | East/West I | North/South J | 1972 | 1973 | 1974 |
| Glass Furnaces | | | | | |
| Thatcher Glass | 04 | 30 | 0.124[a] | 0.124[a] | 0.124[a] |
| Brockway Glass | 26 | 17 | 0.103[a] | 0.103[a] | 0.103[a] |
| Metals Industries | | | | | |
| Kaiser Steel | 33 | 18 | 35.10[b] | 41.36[b] | 38.02[b] |
| Ameron Steel | 32 | 19 | 0.10[c] | 0.10[c] | 0.10[c] |
| Mineral Products | | | | | |
| Crestlite | 29 | -3 | 1.40[d] | 1.00[d] | 1.00[e] |
| Rockwool | 33 | 18 | 0.90[c] | 0.90[c] | 0.90[c] |

References:

(a) Southern California Air Pollution Control District permit file.

(b) See Table A2.10.

(c) Southern California Air Pollution Control District (1976b).

(d) Kaye (1976).

(e) Hunter and Helgeson (1976).

A2.5.6 Sewage Treatment Plant Digesters

Sludge from waste water treatment plants is processed in anaerobic digesters in order to reduce sludge volume and render the residue less offensive. In the process, methane-rich gases containing hydrogen sulfide are generated. This digester gas can be used for fuel. Emissions from power plants and refineries burning digester gas have already been included in the fuel burning portions of this inventory. Digester gas not taken by refineries and power plants is either used to power the treatment plant, or it is incinerated as a waste product. Since it is hard to separate useful fuel burning from waste gas incineration in this inventory, emissions at sewage treatment plants arising from digester gas production were assigned to the digestion process itself. Emissions estimates totaling 0.64 tons per day were made for four major coastal area sewage treatment plants. Emissions estimates for Los Angeles County treatment plants were based on discussion with plant operators. Orange County treatment plant emissions estimates were based on discussion with engineers at the Southern California APCD - Southern Zone offices.

A2.5.7 Permitted Incinerators

Data copied from the APCD permit file contained $SO_x$ emissions estimates for 49 incinerators. About half of these units appear to be pathological incinerators at hospitals and similar institutions. Permit file emissions estimates for all incinerators combined total only 0.074 tons per day. Domestic incinerators are banned in Southern California. Since incinerator emissions are so minor, permit file emissions were accumulated directly to the grid system with no

effort being expended to refine the emission estimates.

A2.6 Mobile Sources

The mobile source emissions inventory is broken down into four classes of highway transportation, plus ships, railroads and aircraft. The categories used to represent mobile source emissions are:

- Automobiles and light trucks - surface streets
- Heavy trucks and buses - surface streets
- Automobiles and light trucks - freeways
- Heavy trucks and buses - freeways
- Airports
- Ship Traffic
- Railroad Operations

The principal reason for subdividing automotive and truck traffic into the four categories shown is to permit a later analysis of the future sulfate air quality impact of oxidation catalyst-equipped vehicles. Catalytic converters were introduced to the vehicle fleet at the start of the 1975 model year in an effort to reduce automotive hydrocarbons and CO emissions. These oxidizing catalysts also are capable of oxidizing a portion of the sulfur originally contained in gasoline to form sulfuric acid mist at the car's tail pipe. A change in the relative proportion of $SO_2$ and $H_2SO_4$ in vehicle exhaust in future years can be modeled conveniently if the catalyst-equipped vehicle $SO_x$ emissions are separable from non-catalyst vehicles in the inventory. Only autos and light trucks are currently being equipped with oxidation catalysts. Freeway and

surface street driving are separated since driving cycle influences catalyst-equipped vehicle sulfuric acid mist emission rates.

A2.6.1 Automobiles and Light Trucks - Surface Streets

Baseline surface street traffic counts have been assembled by Roth et al. (1974) for the 50 by 50 mile grid for the year 1969. These 1969 traffic data are shown in Figure A2.22 in units of thousands of vehicle miles traveled daily in each grid square.

A spatially resolved traffic growth study was conducted to update 1969 surface street traffic density to the 1972 through 1974 period of interest. Annual average traffic counts were acquired for each of the years 1969 through 1974 at 456 street locations spread as evenly as possible across the 50 by 50 mile square. Of these traffic counts, 268 intersections were located on state-maintained surface routes as described by the Califoria Department of Public Works (1969 and 1972) and the California Department of Transportation traffic volume reports (1973 and 1974 editions). Sixty-two traffic samples were taken from the directional traffic flow data of the Orange County Road Departments' Annual Traffic Census (1963 through 1969, 1970 through 1973, and 1974 editions). Data on the remaining 126 locations were hand copied from the traffic count records of the Los Angeles County Road Department and City of Los Angeles Department of Traffic. Whenever data for a given year at some chosen intersection were unavailable, they were estimated by linear interpolation between data for preceeding and following years at that location.

Traffic counts from the sampled intersections were accumulated

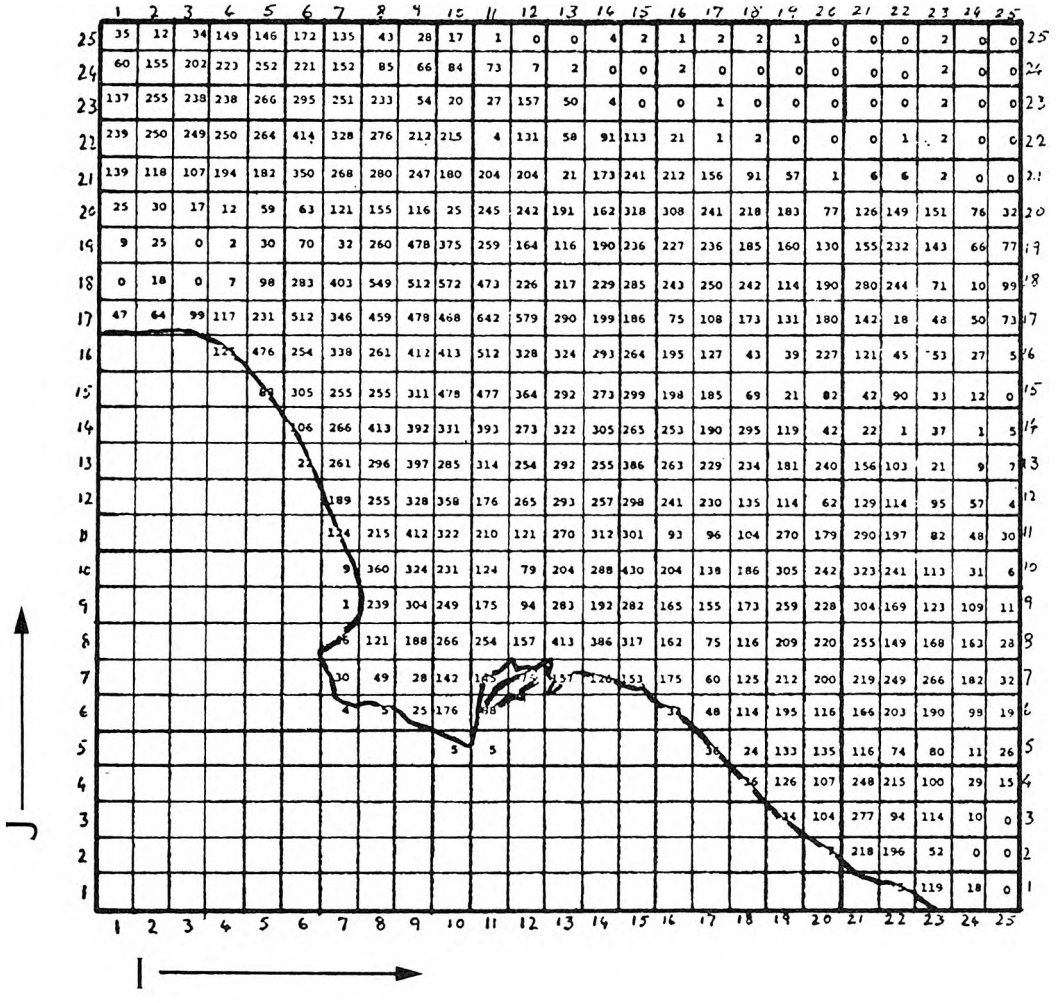



FIGURE A2.22

The Spatial Distribution of Surface Street Traffic--1969
(thousands of vehicle miles traveled
daily within each grid square)
From Roth et al. (1974).

to the grid system. Scale factors needed to represent 1972, 1973 and 1974 traffic counts in each sampled square as a multiple of that square's 1969 sampled traffic were computed. Whenever a given grid cell contained more than one surveyed intersection, the root mean square of the various traffic observations in that grid cell in each year was used as the basis for the scale factor computations.

Next, the scale factors computed based on small traffic samples within individual grid cells were smoothed to better reflect regional traffic growth trends. This smoothing was accomplished by averaging the scale factors computed at all grid cells within a given "neighborhood" composed of nearby cells.

Review of the relationship between our grid system and the air basin's topography led us to form these neighborhoods from the twenty-five large square areas which may be defined by dividing the 50 by 50 mile study area into ten mile by ten mile subdivisions. When this is done, the East and West San Fernando Valleys each occupy one neighborhood, the East and West San Gabriel Valleys each occupy one neighborhood, and major physical traffic barriers (like the Santa Monica Mountains) fall roughly along neighborhood dividing lines.

Scale factors needed to represent 1974 surface street traffic in terms of each grid square's 1969 surface street traffic volume may be converted into compound annual growth rate estimates. The neighborhood-averaged growth rates computed in this manner over the period 1969 through 1974 are given in Figure A2.23. The pattern emerging from those figures indicates (not surprisingly) that surface street traffic growth in the older established portions of central

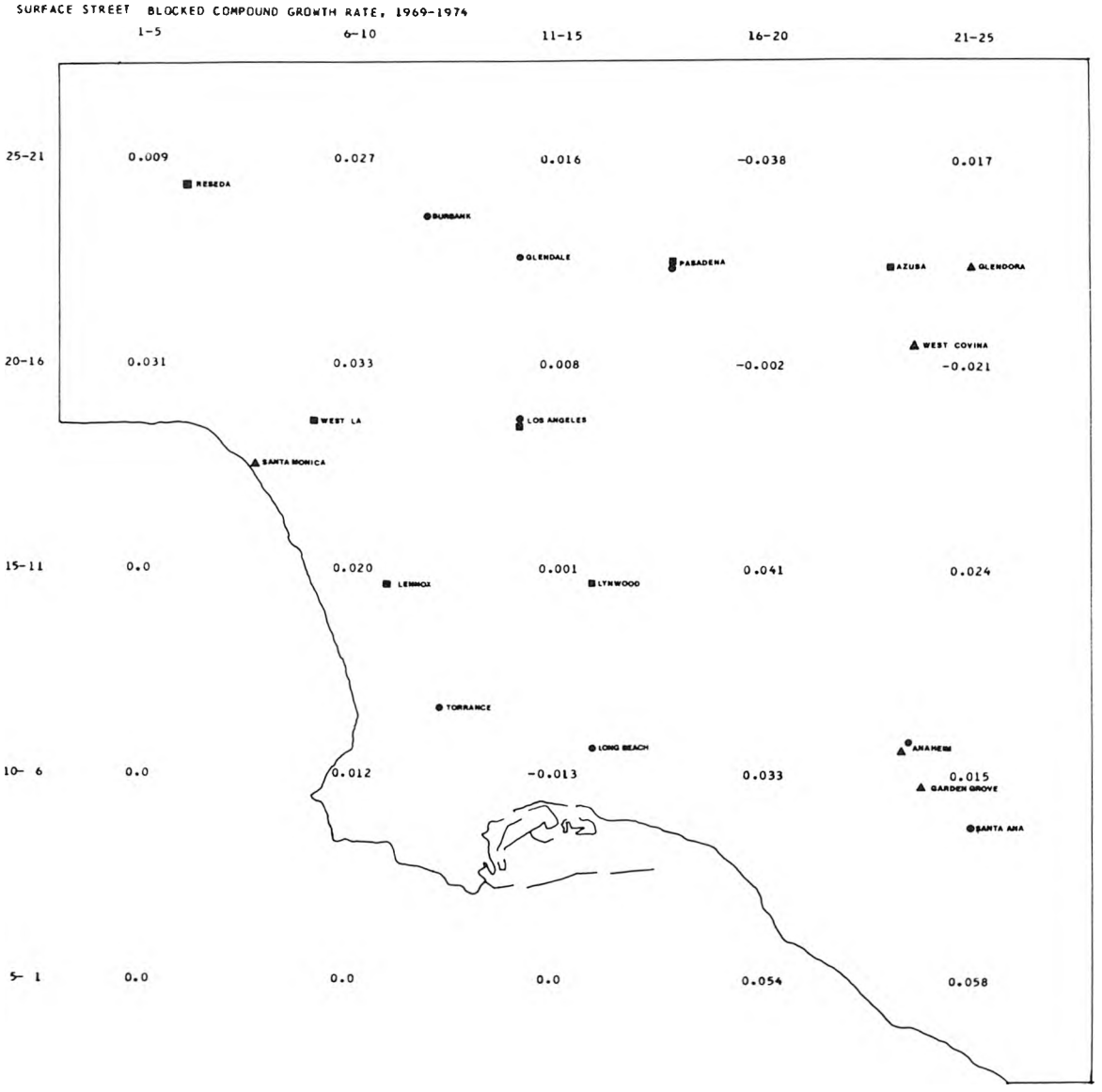



FIGURE A2.23

A Compound Growth Rate Matrix for Surface Street Traffic.

Numbers shown should be multiplied by 100 to obtain growth rates in percent per year.

Los Angeles (e.g. square I 11-15 by J 11-15) over the years from 1969 to 1974 has been practically zero. Meanwhile, rapidly developing coastal Orange County (squares I 15-20 by J 5-1 and I 21-25 by J 5-1) has seen compound traffic growth rates of about 6% annually averaged over the period 1969 through 1974 resulting in about one third more vehicle miles traveled in 1974 than in 1969. The high traffic growth area of Los Angeles County appears to be West Los Angeles and the Santa Monica mountains. The decline in surface street traffic in portions of the San Gabriel Valley (square I 16-20 by J 25-21) may be due to the diversion of traffic onto several recently completed freeways.

Scale factors averaged over each neighborhood were assigned to each individual 2 mile by 2 mile square in that neighborhood. The resulting matrices were then used to scale the 1969 surface street traffic counts of Figure A2.22 to the years 1972, 1973 and 1974 as shown in Figures A2.24 through A2.26. Total surface street traffic in 1974 is estimated to average 79,376,000 vehicle miles traveled per day within the 50 by 50 mile study area.

The annual average daily traffic densities given in Figures A2.24 through A2.26 were then used to compute automobile and light duty truck $SO_x$ emissions on a spatially resolved basis. Total surface street traffic density was uniformly apportioned to vehicle miles traveled daily by automobiles, light trucks, heavy duty gasoline trucks and buses, and diesel trucks and buses according to the fraction of total VMT driven by each vehicle type as given in Table A2.12. Average automobile and light truck miles traveled

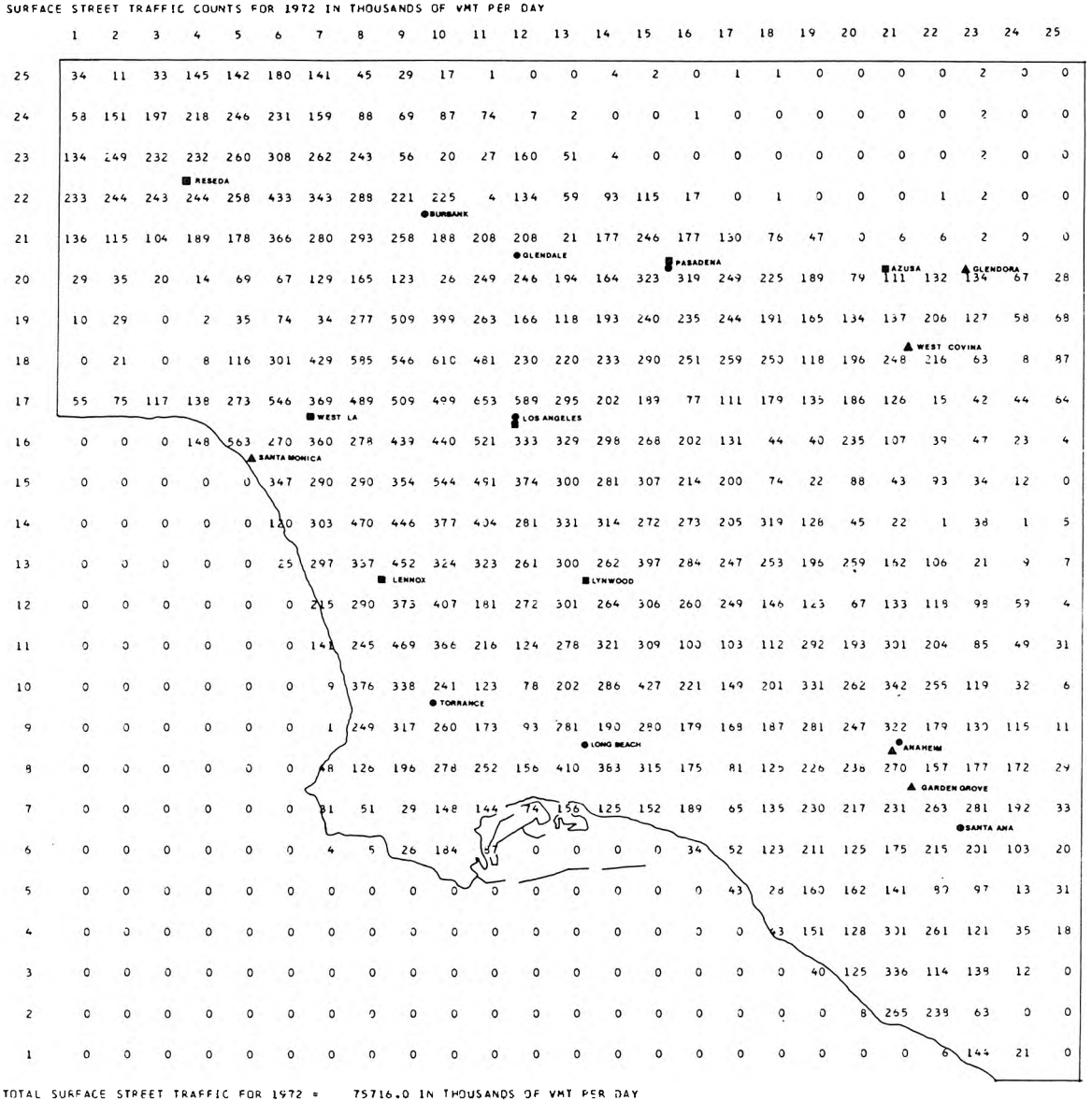

SURFACE STREET TRAFFIC COUNTS FOR 1972 IN THOUSANDS OF VMT PER DAY
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
25 34 11 33 145 142 180 141 45 29 17 1 0 0 4 2 0 1 1 0 0 0 0 2 0 0
24 58 151 197 218 246 231 159 88 69 87 74 7 2 0 0 1 0 0 0 0 0 0 2 0 0
23 134 249 232 232 260 308 262 243 56 20 27 160 51 4 0 0 0 0 0 0 0 0 2 0 0
22 233 244 243 244 258 433 343 288 221 225 4 134 59 93 115 17 0 1 0 0 0 1 2 0 0
21 136 115 104 189 178 366 280 293 258 188 208 208 21 177 246 177 130 76 47 0 6 6 2 0 0
20 29 35 20 14 69 67 129 165 123 26 249 246 194 164 323 319 249 225 189 79 111 132 134 67 28
19 10 29 0 2 35 74 34 277 509 399 263 166 118 193 240 235 244 191 165 134 137 206 127 58 68
18 0 21 0 8 116 301 429 585 546 610 481 230 220 233 290 251 259 250 118 196 248 216 63 8 87
17 55 75 117 138 273 546 369 489 509 499 653 589 295 202 189 77 111 179 135 186 126 15 42 44 64
16 0 0 0 148 563 270 360 278 439 440 521 333 329 298 268 202 131 44 40 235 107 39 47 23 4
15 0 0 0 0 0 347 290 290 354 544 491 374 300 281 307 214 200 74 22 88 43 93 34 12 0
14 0 0 0 0 0 120 303 470 446 377 404 281 331 314 272 273 205 319 128 45 22 1 38 1 5
13 0 0 0 0 0 25 297 357 452 324 323 261 300 262 397 284 247 253 196 259 142 106 21 9 7
12 0 0 0 0 0 0 215 290 373 407 181 272 301 264 306 260 249 146 143 67 133 119 98 59 4
11 0 0 0 0 0 0 141 245 469 366 216 124 278 321 309 100 103 112 292 193 301 204 85 49 31
10 0 0 0 0 0 0 9 376 338 241 123 78 202 286 427 221 149 201 331 262 342 255 119 32 6
9 0 0 0 0 0 0 1 249 317 260 173 93 281 190 280 179 168 187 281 247 322 179 130 115 11
8 0 0 0 0 0 0 48 126 196 278 252 156 410 383 315 175 81 125 226 236 270 157 177 172 29
7 0 0 0 0 0 0 31 51 29 148 144 74 158 125 152 189 65 135 230 217 231 263 281 192 33
6 0 0 0 0 0 0 4 5 26 184 37 0 0 0 0 34 52 123 211 125 175 215 201 103 20
5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 43 28 160 162 141 97 97 13 31
4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 43 151 128 301 261 121 35 18
3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 40 125 336 114 139 12 0
2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 8 265 239 63 0 0
1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 144 21 0
RESEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
TOTAL SURFACE STREET TRAFFIC FOR 1972 = 75716.0 IN THOUSANDS OF VMT PER DAY

FIGURE A2.24

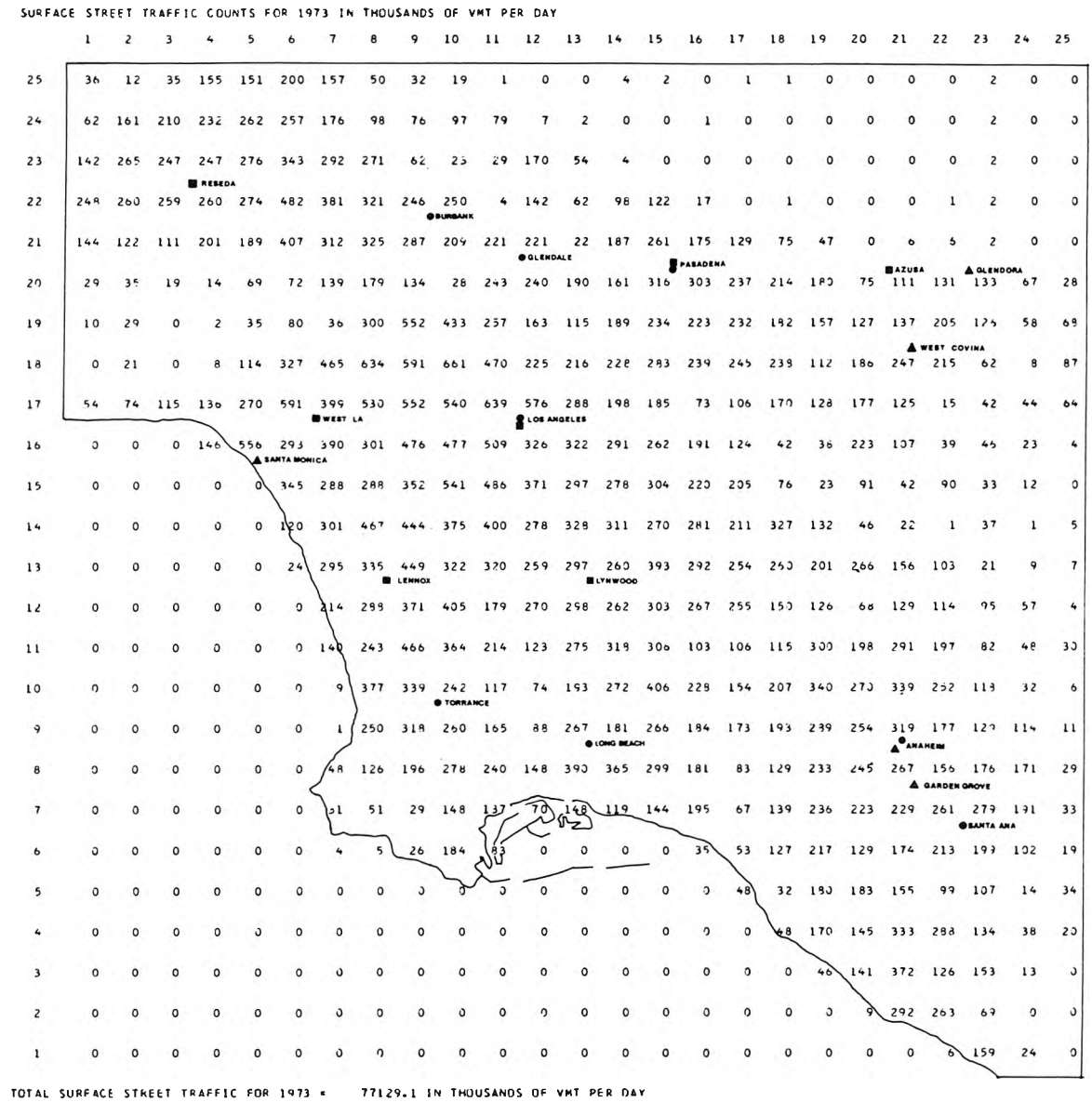

SURFACE STREET TRAFFIC COUNTS FOR 1973 IN THOUSANDS OF VMT PER DAY
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
25 36 12 35 155 151 200 157 50 32 19 1 0 0 4 2 0 1 1 0 0 0 0 2 0 0
24 62 161 210 232 262 257 176 98 76 97 79 7 2 0 0 1 0 0 0 0 0 0 2 0 0
23 142 265 247 247 276 343 292 271 62 25 29 170 54 4 0 0 0 0 0 0 0 0 2 0 0
22 248 260 259 260 274 482 381 321 246 250 4 142 62 98 122 17 0 1 0 0 0 1 2 0 0
21 144 122 111 201 189 407 312 325 287 209 221 221 22 187 261 175 129 75 47 0 6 5 2 0 0
20 29 35 19 14 69 72 139 179 134 28 243 240 190 161 316 303 237 214 180 75 111 131 133 67 28
19 10 29 0 2 35 80 36 300 552 433 257 163 115 189 234 223 232 182 157 127 137 205 125 58 68
18 0 21 0 8 114 327 465 634 591 661 470 225 216 228 283 239 245 238 112 186 247 215 62 8 87
17 54 74 115 136 270 591 395 530 552 540 639 576 288 198 185 73 106 170 128 177 125 15 42 44 64
16 0 0 0 146 556 293 390 301 476 477 509 326 322 291 262 191 124 42 38 223 107 39 46 23 4
15 0 0 0 0 0 345 288 288 352 541 486 371 297 278 304 220 205 76 23 91 42 90 33 12 0
14 0 0 0 0 0 120 301 467 444 375 400 278 328 311 270 281 211 327 132 46 22 1 37 1 5
13 0 0 0 0 0 24 295 335 449 322 320 259 297 260 393 292 254 260 201 266 156 103 21 9 7
12 0 0 0 0 0 0 214 288 371 405 179 270 258 262 303 267 255 150 126 68 129 114 95 57 4
11 0 0 0 0 0 0 140 243 466 364 214 123 275 318 306 103 106 115 300 198 291 197 82 48 30
10 0 0 0 0 0 0 9 377 339 242 117 74 193 272 406 228 154 207 340 270 339 252 113 32 6
9 0 0 0 0 0 0 1 250 318 260 165 88 267 181 266 184 173 193 239 254 319 177 120 114 11
8 0 0 0 0 0 0 48 126 196 278 240 148 390 365 299 181 83 129 233 245 267 156 176 171 29
7 0 0 0 0 0 0 61 51 29 148 137 70 148 119 144 195 67 139 236 223 229 261 279 191 33
6 0 0 0 0 0 0 4 5 26 184 83 0 0 0 0 35 53 127 217 129 174 213 193 102 19
5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 48 32 180 183 155 99 107 14 34
4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 48 170 145 333 288 134 38 20
3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 46 141 372 126 153 13 0
2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 292 263 69 0 0
1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 159 24 0
RESEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
TOTAL SURFACE STREET TRAFFIC FOR 1973 = 77129.1 IN THOUSANDS OF VMT PER DAY

FIGURE A2.25

SURFACE STREET TRAFFIC COUNTS FOR 1974 IN THOUSANDS OF VMT PER DAY

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 37 | 12 | 36 | 160 | 157 | 202 | 158 | 50 | 32 | 20 | 1 | 0 | 0 | 4 | 2 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| 24 | 64 | 166 | 217 | 240 | 271 | 260 | 178 | 100 | 77 | 98 | 79 | 7 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| 23 | 147 | 274 | 256 | 256 | 286 | 347 | 295 | 274 | 63 | 23 | 29 | 171 | 54 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| 22 | 257 | 269 | 268 | 269 | 284 | 487 | 386 | 324 | 249 | 253 | 4 | 143 | 63 | 99 | 123 | 17 | 0 | 1 | 0 | 0 | 0 | 1 | 2 | 0 | 0 |
| 21 | 149 | 127 | 115 | 208 | 196 | 412 | 315 | 329 | 290 | 211 | 223 | 223 | 22 | 189 | 263 | 175 | 129 | 75 | 47 | 0 | 6 | 6 | 2 | 0 | 0 |
| 20 | 29 | 35 | 20 | 14 | 70 | 75 | 145 | 186 | 139 | 30 | 258 | 255 | 201 | 171 | 335 | 307 | 240 | 217 | 182 | 76 | 114 | 135 | 137 | 69 | 29 |
| 19 | 10 | 29 | 0 | 2 | 35 | 84 | 38 | 313 | 576 | 452 | 273 | 173 | 122 | 200 | 249 | 226 | 235 | 184 | 159 | 129 | 140 | 210 | 129 | 59 | 69 |
| 18 | 0 | 21 | 0 | 8 | 117 | 341 | 485 | 661 | 617 | 689 | 499 | 238 | 229 | 241 | 300 | 242 | 249 | 241 | 113 | 189 | 254 | 221 | 64 | 9 | 89 |
| 17 | 56 | 76 | 118 | 140 | 277 | 617 | 417 | 553 | 576 | 564 | 677 | 611 | 306 | 210 | 196 | 74 | 107 | 172 | 130 | 179 | 129 | 16 | 43 | 45 | 66 |
| 16 | 0 | 0 | 0 | 149 | 570 | 306 | 407 | 314 | 496 | 497 | 540 | 346 | 342 | 309 | 278 | 194 | 126 | 42 | 38 | 226 | 109 | 40 | 48 | 24 | 4 |
| 15 | 0 | 0 | 0 | 0 | 0 | 339 | 283 | 283 | 345 | 531 | 484 | 365 | 296 | 277 | 303 | 243 | 227 | 84 | 25 | 100 | 48 | 104 | 38 | 13 | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 | 117 | 295 | 459 | 435 | 368 | 399 | 277 | 327 | 309 | 269 | 310 | 233 | 362 | 146 | 51 | 25 | 1 | 43 | 1 | 5 |
| 13 | 0 | 0 | 0 | 0 | 0 | 24 | 290 | 329 | 441 | 316 | 319 | 258 | 296 | 259 | 392 | 322 | 281 | 287 | 222 | 294 | 181 | 119 | 24 | 10 | 8 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 210 | 283 | 364 | 398 | 178 | 269 | 297 | 261 | 302 | 295 | 282 | 165 | 139 | 76 | 150 | 132 | 110 | 66 | 4 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 137 | 239 | 458 | 358 | 213 | 122 | 274 | 317 | 305 | 114 | 117 | 127 | 331 | 219 | 337 | 229 | 95 | 55 | 34 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 383 | 345 | 248 | 116 | 74 | 191 | 270 | 403 | 241 | 163 | 220 | 361 | 287 | 350 | 261 | 122 | 33 | 6 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 254 | 324 | 265 | 164 | 88 | 265 | 180 | 264 | 195 | 183 | 205 | 307 | 270 | 329 | 183 | 133 | 118 | 11 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 49 | 129 | 200 | 283 | 238 | 147 | 387 | 362 | 297 | 192 | 88 | 137 | 247 | 260 | 276 | 161 | 182 | 176 | 30 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 31 | 52 | 29 | 151 | 136 | 70 | 147 | 118 | 143 | 207 | 71 | 148 | 251 | 237 | 237 | 270 | 288 | 197 | 34 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 5 | 26 | 187 | 82 | 0 | 0 | 0 | 0 | 37 | 56 | 135 | 231 | 137 | 180 | 220 | 206 | 106 | 20 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 47 | 91 | 175 | 177 | 158 | 101 | 109 | 15 | 35 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 47 | 165 | 140 | 338 | 233 | 136 | 39 | 20 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 44 | 136 | 378 | 128 | 155 | 13 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 297 | 267 | 73 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 162 | 24 | 0 |

REBEDA, BURBANK, GLENDALE, PASADENA, AZUSA, GLENDORA, WEST COVINA, WEST LA, LOS ANGELES, SANTA MONICA, LENNOX, LYNWOOD, TORRANCE, LONG BEACH, ANAHEIM, GARDEN GROVE, SANTA ANA

TOTAL SURFACE STREET TRAFFIC FOR 1974 = 79375.8 IN THOUSANDS OF VMT PER DAY

FIGURE A2.26

TABLE A2.12

Percentage of Vehicle Miles Traveled
and Fuel Economy for each Vehicle Type

| Vehicle Type | Percent of Total Vehicle Miles Traveled | Fuel Economy (mpg) |
|---|---|---|
| Light Duty Autos | 80.4% | 13.6 |
| Light Duty Trucks | 11.8% | 10.0 |
| Heavy Duty Trucks (Gasoline) | 4.6% | 6.0 |
| Heavy Duty Trucks and Buses (Diesel) | 3.2% | 4.6 |

Reference: Environmental Protection Agency (1975)
(Nationwide vehicle mix)

daily were converted to annual average fuel quantities consumed in each grid cell daily using the fuel economy data in Table A2.12. Then the monthly variation about the annual average daily gasoline consumption in each square was estimated in proportion to the relative variation in total gasoline sales in California reported for each month of that year by the Ethyl Corporation (1974).

Having determined a time history of light duty vehicle gasoline use on surface streets for each month, sulfur oxides emissions for each month from this source class were calculated on the basis of gasoline sulfur content data given by the Bureau of Mines as shown in Table A2.13. Light duty vehicle surface street sulfur oxides emissions for a typical month in 1973 are shown in Figure A2.27.

A2.6.2 Heavy Duty Trucks and Buses - Surface Streets

$SO_x$ emissions from heavy duty trucks and buses were estimated by a procedure analogous to that for light duty vehicles. The fraction of surface street traffic driven by each of these vehicle types is again listed in Table A2.12. The sulfur content of the gasoline pool is again given in Table A2.13. The sulfur content of diesel fuel is taken from Bureau of Mines data which are also shown in Table A2.13. Since data on the seasonal variations in diesel fuel sales are unknown to us, the seasonal variation in vehicle miles traveled is again taken as proportional to monthly fluctuations in gasoline sales volume in California.

The resulting calculated heavy duty vehicle $SO_x$ emissions pattern is shown in Figure A2.28 for a typical month in 1973. Total

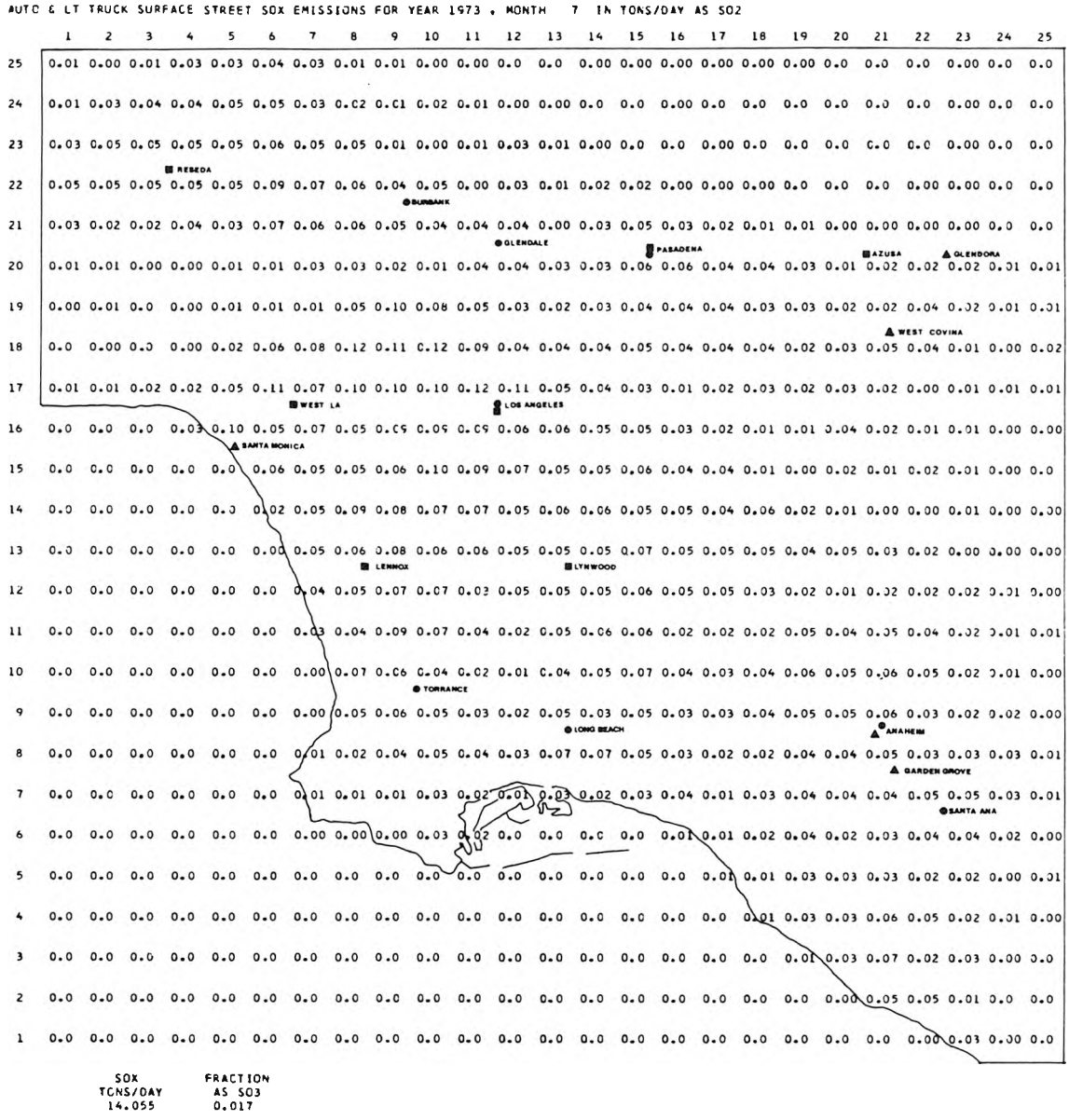
TABLE A2.13

Sulfur Content of Vehicle Fuels

| Fuel Type | Period | Average Sulfur Content (% by Weight) | | |
|---|---|---|---|---|
| | | Regular Gasoline | Premium Gasoline | Diesel Fuels |
| Gasoline[a] | | | | |
| | Winter 1971-72 | 0.095 | 0.041 | |
| | Summer 1972 | 0.061 | 0.042 | |
| | Winter 1972-73 | 0.069 | 0.042 | |
| | Summer 1973 | 0.046 | 0.034 | |
| | Winter 1973-74 | 0.061 | 0.039 | |
| | Summer 1974 | 0.057 | 0.033 | |
| | Winter 1974-75 | 0.067 | 0.045 | |
| Diesel Fuel[b] | 1972 | | | 0.218 |
| | 1973 | | | 0.230 |
| | 1974 | | | 0.265 |

References: (a) Bureau of Mines (1972f through 1975f) and Energy Research and Development Administration Petroleum Product Survey Series, for example the study referenced to Shelton (1975).

(b) Bureau of Mines (1972d through 1975d).


AUTO & LT TRUCK SURFACE STREET SOX EMISSIONS FOR YEAR 1973 , MONTH 7 IN TONS/DAY AS SO2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
25 0.01 0.00 0.01 0.03 0.03 0.04 0.03 0.01 0.01 0.00 0.00 0.0 0.0 0.00 0.00 0.00 0.00 0.00 0.00 0.0 0.0 0.0 0.00 0.0 0.0
24 0.01 0.03 0.04 0.04 0.05 0.05 0.03 0.02 0.01 0.02 0.01 0.00 0.00 0.0 0.0 0.00 0.0 0.0 0.0 0.0 0.0 0.0 0.00 0.0 0.0
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22 0.05 0.05 0.05 0.05 0.05 0.09 0.07 0.06 0.04 0.05 0.00 0.03 0.01 0.02 0.02 0.00 0.00 0.00 0.0 0.0 0.0 0.00 0.00 0.0 0.0
21 0.03 0.02 0.02 0.04 0.03 0.07 0.06 0.06 0.05 0.04 0.04 0.04 0.00 0.03 0.05 0.03 0.02 0.01 0.01 0.00 0.00 0.00 0.00 0.0 0.0
20 0.01 0.01 0.00 0.00 0.01 0.01 0.03 0.03 0.02 0.01 0.04 0.04 0.03 0.03 0.06 0.06 0.04 0.04 0.03 0.01 0.02 0.02 0.02 0.01 0.01
19 0.00 0.01 0.0 0.00 0.01 0.01 0.01 0.05 0.10 0.08 0.05 0.03 0.02 0.03 0.04 0.04 0.04 0.03 0.03 0.02 0.02 0.04 0.02 0.01 0.01
18 0.0 0.00 0.0 0.00 0.02 0.06 0.08 0.12 0.11 0.12 0.09 0.04 0.04 0.04 0.05 0.04 0.04 0.04 0.02 0.03 0.05 0.04 0.01 0.00 0.02
17 0.01 0.01 0.02 0.02 0.05 0.11 0.07 0.10 0.10 0.10 0.12 0.11 0.05 0.04 0.03 0.01 0.02 0.03 0.02 0.03 0.02 0.00 0.01 0.01 0.01
16 0.0 0.0 0.0 0.03 0.10 0.05 0.07 0.05 0.09 0.09 0.09 0.06 0.06 0.05 0.05 0.03 0.02 0.01 0.01 0.04 0.02 0.01 0.01 0.00 0.00
15 0.0 0.0 0.0 0.0 0.0 0.06 0.05 0.05 0.06 0.10 0.09 0.07 0.05 0.05 0.06 0.04 0.04 0.01 0.00 0.02 0.01 0.02 0.01 0.00 0.0
14 0.0 0.0 0.0 0.0 0.0 0.02 0.05 0.09 0.08 0.07 0.07 0.05 0.06 0.06 0.05 0.05 0.04 0.06 0.02 0.01 0.00 0.00 0.01 0.00 0.00
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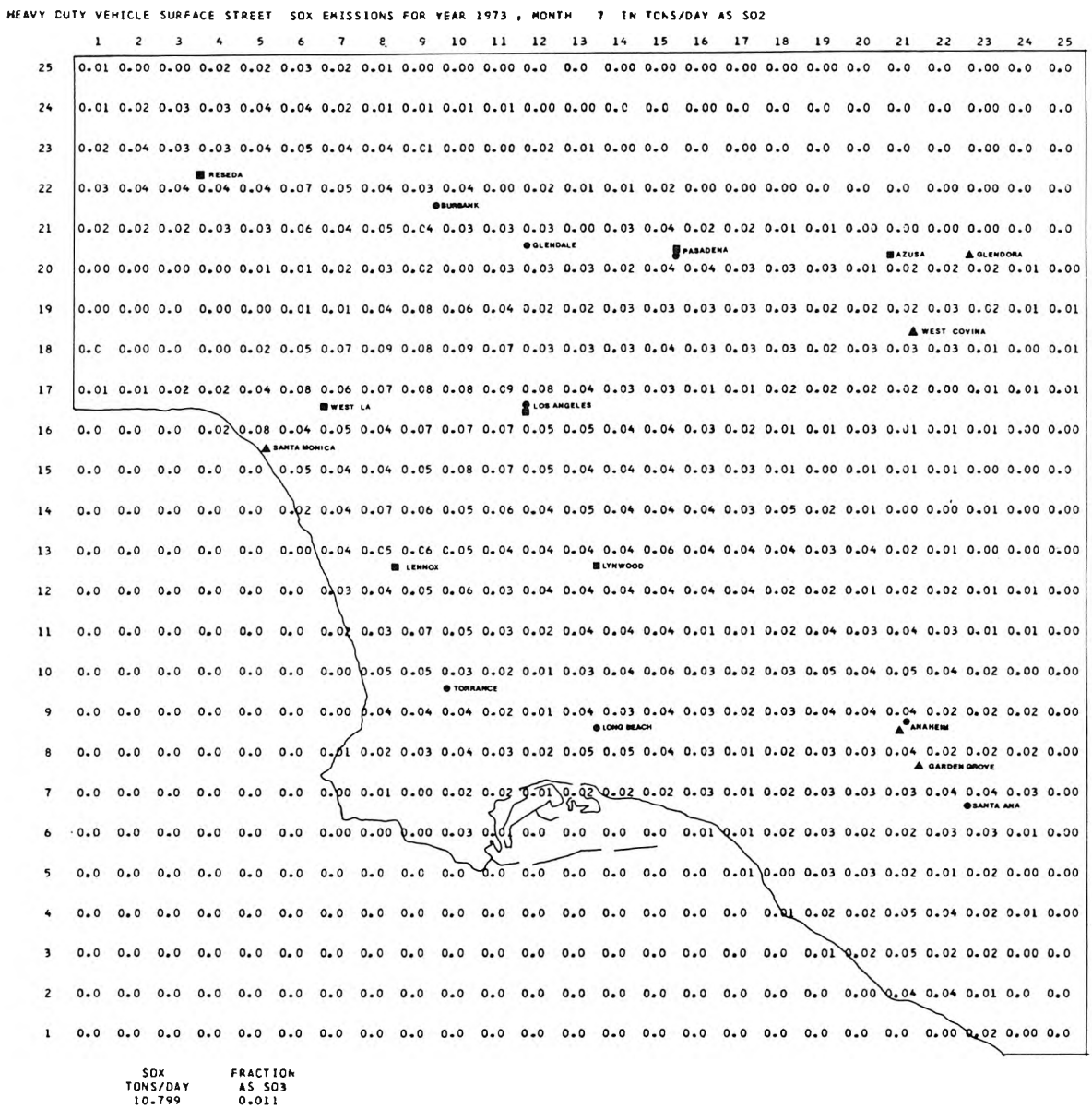
REDEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
SOX TONS/DAY 14.055
FRACTION AS SO3 0.017

FIGURE A2.27


HEAVY DUTY VEHICLE SURFACE STREET SOX EMISSIONS FOR YEAR 1973 , MONTH 7 IN TONS/DAY AS SO2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
25 0.01 0.00 0.00 0.02 0.02 0.03 0.02 0.01 0.00 0.00 0.00 0.0 0.0 0.00 0.00 0.00 0.00 0.00 0.00 0.0 0.0 0.0 0.00 0.0 0.0
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17 0.01 0.01 0.02 0.02 0.04 0.08 0.06 0.07 0.08 0.08 0.09 0.08 0.04 0.03 0.03 0.01 0.01 0.02 0.02 0.02 0.02 0.00 0.01 0.01 0.01
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RESEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
SOX TONS/DAY 10.799
FRACTION AS SO3 0.011

FIGURE A2.28

$SO_x$ emissions from heavy duty vehicles are only slightly smaller than from light duty vehicles even though heavy duty vehicle miles traveled are modest by comparison to automotive and light truck travel. This is due to the higher sulfur content of diesel fuel combined with the greater fuel consumption per mile driven by larger vehicles.

A2.6.3 Automobiles and Light Trucks - Freeway

While surface street traffic patterns had to be established by "growing" historic data up to the years of interest using several hundred spot checks, sufficient data exist to completely recount freeway traffic flows from scratch. Virtually all freeway mileage within our study area is part of the state highway system. Because of the importance of freeway traffic flow to the regional transportation system in Los Angeles, the California Department of Transportation (Cal Trans) maintains a dense network of traffic gauging points at nearly every freeway on-ramp or interchange. Each gauging point is assigned a milepost number. The difference between the milepost numbers at two consecutive traffic counting points gives one the length of the freeway segment (in miles) located between those two mileposts. Between each pair of mileposts, traffic counts are given listing the average number of vehicles using that stretch of highway daily during each year of interest. By multiplying road segment length by the number of vehicles transiting each segment daily, one can calculate annual average vehicle miles traveled (VMT) daily on the freeway system in any recent year.

The difficult part of the freeway traffic counting procedure arises when one tries to assign traffic counts geographically to our grid system. Because of the relatively fine spacing of our 2 mile by 2 mile grid cells, road segments between mileposts usually intersect grid cell boundaries. When this occurs, appropriate fractions of a road segment's traffic flow must be assigned to two or sometimes three grid cells. Secondly, because of the large number of freeways in the Los Angeles area and their often meandering roadbeds, a number of pathological grid cell traffic assignment situations arise in which a freeway literally lies on a grid cell boundary for a portion of its length, or passes through adjacent cell boundaries at a very oblique angle. Finally, certain California Department of Transportation mileposts are assigned by name to freeway interchanges or on-ramp complexes which themselves are several tenths of a mile in length. It is not always clear from looking at a freeway map exactly where some road segments start or end. This latter problem is compounded by Cal Trans' practice of making occasional small adjustments in milepost numbers representing the same intersection in consecutive years.

The above discussion is intended to indicate that a freeway traffic counting procedure using the available data is not as straightforward as it might seem at first glance. The person doing the work must continually exercise his judgment in close situations. Two groups of people carefully following the same instructions will certainly come to a slightly different geographic distribution of traffic flows on this freeway system. Realizing this, we first

attempted to reproduce the baseline freeway traffic counts for the year 1969 given by Roth, et al. (1974). This attempted reproduction of Roth, et al.'s work would serve as a check on gross errors in assignment of freeway segments to individual grid cells. Once the freeway segments are properly located, it is relatively easy to count traffic in a consistent manner in later years.

The 50 by 50 mile square grid was transferred to a street map drawn to a scale of 2800 feet to the inch (Thomas Brothers Maps, 1975). Grid alignment was adjusted until it closely followed the surface street locations shown on our grid system reference map obtained from the APCD (Taylor, 1976) and also the 1969 freeway map provided by Roth, et al., 1974, as shown in Figure A2.29.

Next, freeway segments defined by the milepost locations given by the California Department of Transportation (1974) were assigned to the grid squares in which they resided. Single freeway segments falling across grid square boundaries were assigned to the appropriate grid cells in proportion to the fraction of freeway segment length in each cell. Over seven hundred freeway fragments were thus defined. Freeway segments completed in the latter years of our study period were entered as having zero traffic in years prior to their construction. Special adjustments were made for a few cases in which the 1974 grid square location of a given route did not reflect its physical location in some prior year(s) due to freeway reconstruction or rerouting.

Annual average daily traffic volumes given by the California

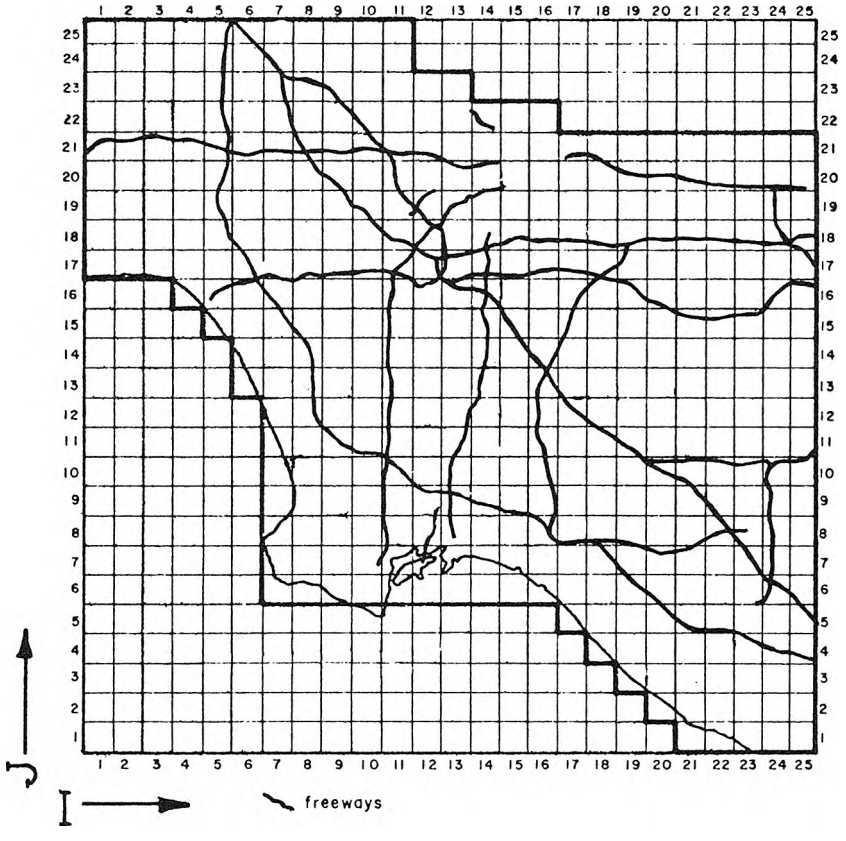



FIGURE A2.29

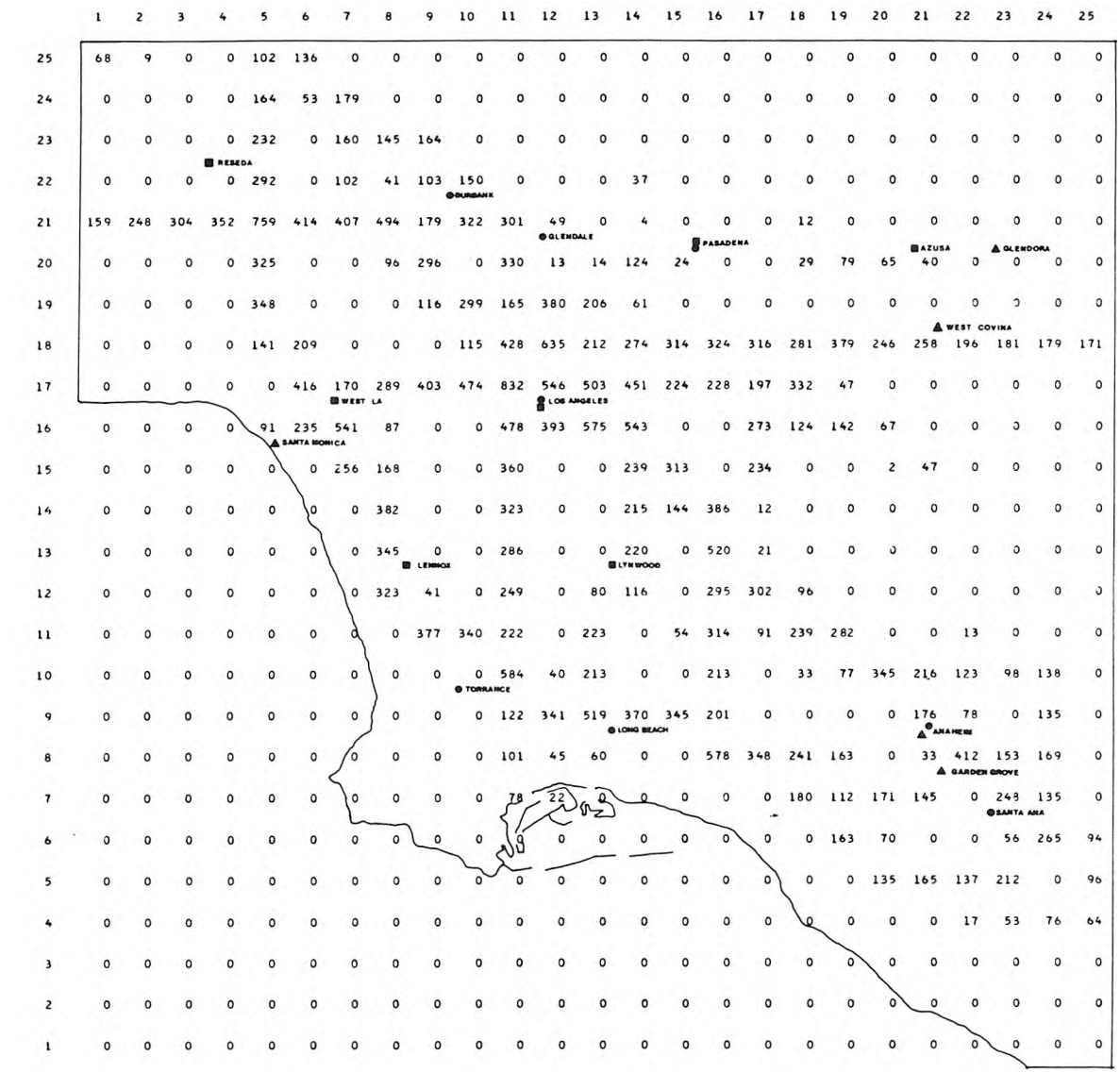
The Modeling Region
(showing Roth et al.'s (1974) grid network and the Los Angeles freeway system as it existed in 1969).

Department of Public Works (1969 and 1972) and California Department of Transportation (1973 and 1974) were associated with each freeway segment or fraction thereof in each of the years 1969, 1972, 1973 and 1974, then multiplied by road length to obtain vehicle miles traveled per day. All traffic counts within a grid cell were then added together for each year to obtain the freeway traffic count maps shown in Figures A2.30 through A2.33.

Average freeway traffic volume in 1969 from our survey totaled 40,155 thousand vehicle miles traveled daily within the 50 by 50 mile square. That value is within 4.3% of the 41,926 thousand vehicle miles traveled daily on freeways in 1969 as reported by Roth, et al. (1974) as shown in Figure A2.34. When Roth, et al.'s traffic pattern in 1969 is subtracted from ours on a square by square basis, a difference map is obtained. About half of the occupied grid cell traffic estimates are within 10% or 10 thousand VMT of each other on a cell by cell basis. Each of the grid cells in which tight agreement was not obtained were examined more closely. Several good reasons for disagreement were uncovered.

For example, Roth, et al. report freeway traffic in numerous grid cells near the right hand side of the 50 by 50 mile square (columns I21 through I25) in which we show no freeway traffic in 1969. The reason for this discrepancy apparently arises from a difference in the definition of what constitutes a freeway. We have used the California Department of Transportation's definition of freeway starting locations as given in the state's traffic volume books (California Department of Public Works, 1969). In 1969, however,

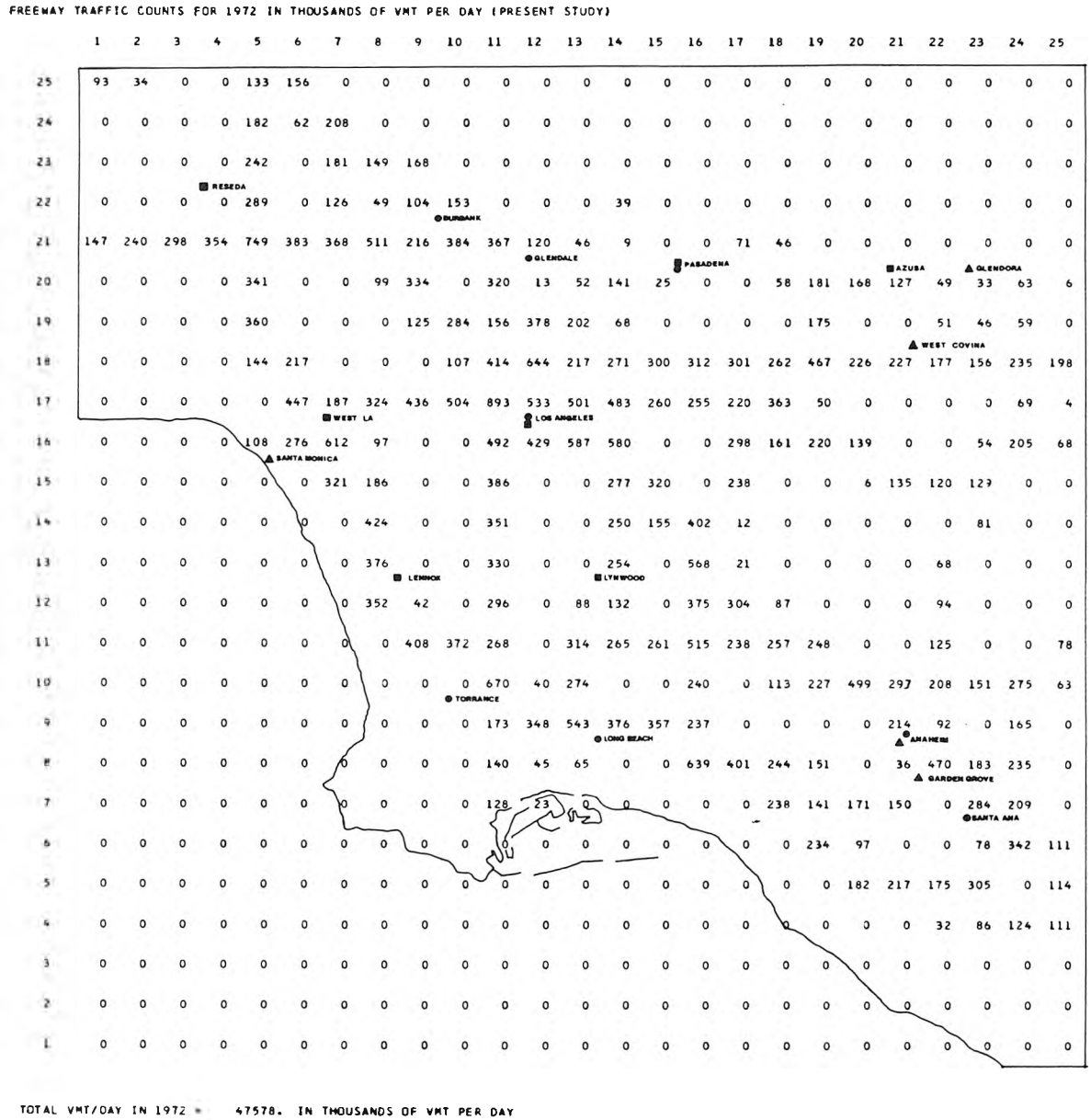
FREEWAY TRAFFIC COUNTS FOR 1969 IN THOUSANDS OF VMT PER DAY (PRESENT STUDY)




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 68 | 9 | 0 | 0 | 102 | 136 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 164 | 53 | 179 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 232 | 0 | 160 | 145 | 164 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0 | 0 | 292 | 0 | 102 | 41 | 103 | 150 | 0 | 0 | 0 | 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 159 | 248 | 304 | 352 | 759 | 414 | 407 | 494 | 179 | 322 | 301 | 49 | 0 | 4 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 325 | 0 | 0 | 96 | 296 | 0 | 330 | 13 | 14 | 124 | 24 | 0 | 0 | 29 | 79 | 65 | 40 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 348 | 0 | 0 | 0 | 116 | 299 | 165 | 380 | 206 | 61 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 0 | 141 | 209 | 0 | 0 | 0 | 115 | 428 | 635 | 212 | 274 | 314 | 324 | 316 | 281 | 379 | 246 | 258 | 196 | 181 | 179 | 171 |
| 17 | 0 | 0 | 0 | 0 | 0 | 416 | 170 | 289 | 403 | 474 | 832 | 546 | 503 | 451 | 224 | 228 | 197 | 332 | 47 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 91 | 235 | 541 | 87 | 0 | 0 | 478 | 393 | 575 | 543 | 0 | 0 | 273 | 124 | 142 | 67 | 0 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 256 | 168 | 0 | 0 | 360 | 0 | 0 | 239 | 313 | 0 | 234 | 0 | 0 | 2 | 47 | 0 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 382 | 0 | 0 | 323 | 0 | 0 | 215 | 144 | 386 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 345 | 0 | 0 | 286 | 0 | 0 | 220 | 0 | 520 | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 323 | 41 | 0 | 249 | 0 | 80 | 116 | 0 | 295 | 302 | 96 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 377 | 340 | 222 | 0 | 223 | 0 | 54 | 314 | 91 | 239 | 282 | 0 | 0 | 13 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 584 | 40 | 213 | 0 | 0 | 213 | 0 | 33 | 77 | 345 | 216 | 123 | 98 | 138 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 122 | 341 | 519 | 370 | 345 | 201 | 0 | 0 | 0 | 0 | 176 | 78 | 0 | 135 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 101 | 45 | 60 | 0 | 0 | 578 | 348 | 241 | 163 | 0 | 33 | 412 | 153 | 169 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 78 | 22 | 0 | 0 | 0 | 0 | 0 | 180 | 112 | 171 | 145 | 0 | 248 | 135 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 163 | 70 | 0 | 0 | 56 | 265 | 94 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 135 | 165 | 137 | 212 | 0 | 96 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17 | 53 | 76 | 64 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

TOTAL VMT/DAY IN 1969 = 40155. IN THOUSANDS OF VMT PER DAY

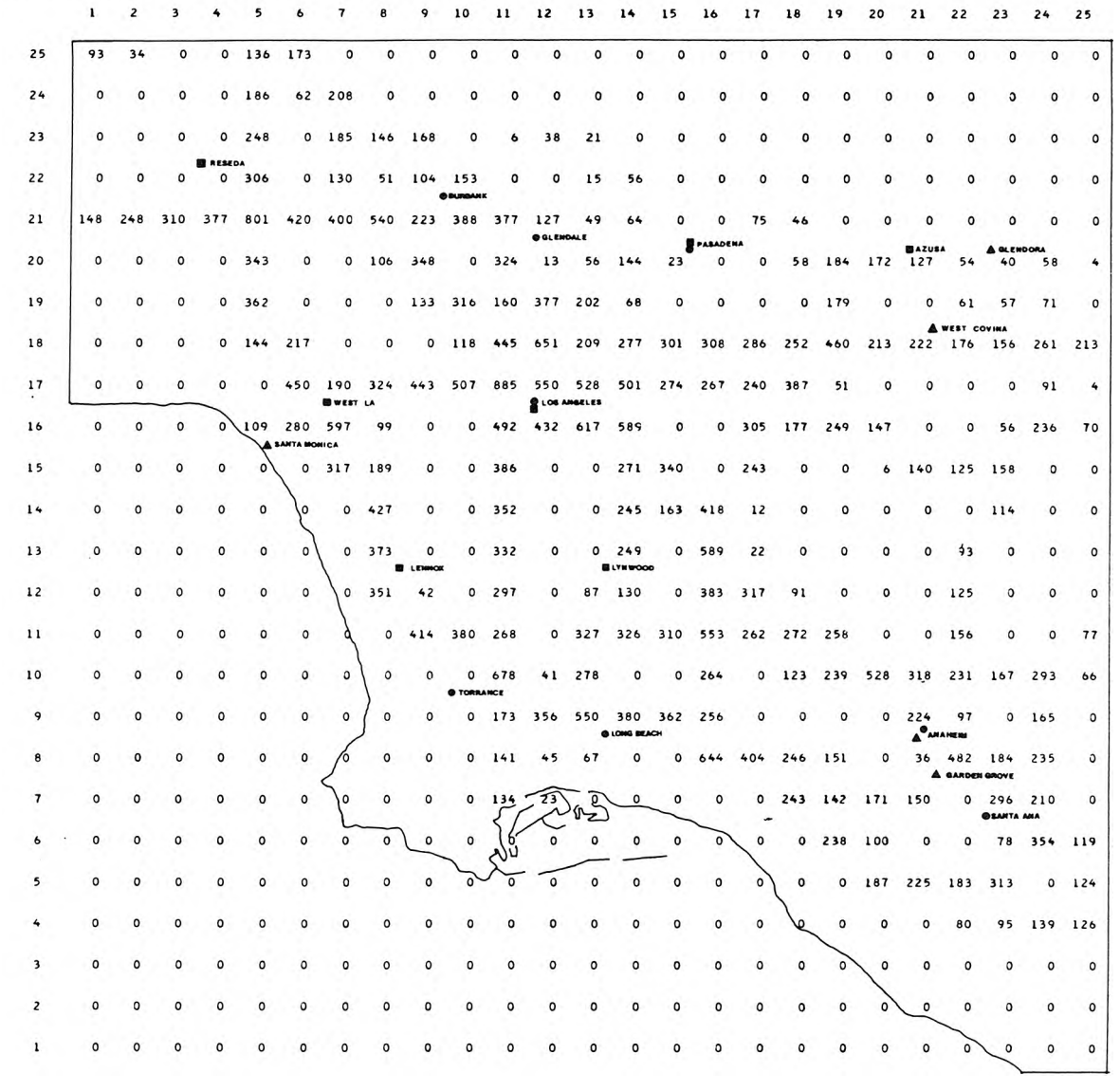
FIGURE A2.30




TOTAL VMT/DAY IN 1972 = 47578. IN THOUSANDS OF VMT PER DAY

FIGURE A2.31

FREEWAY TRAFFIC COUNTS FOR 1973 IN THOUSANDS OF VMT PER DAY (PRESENT STUDY)



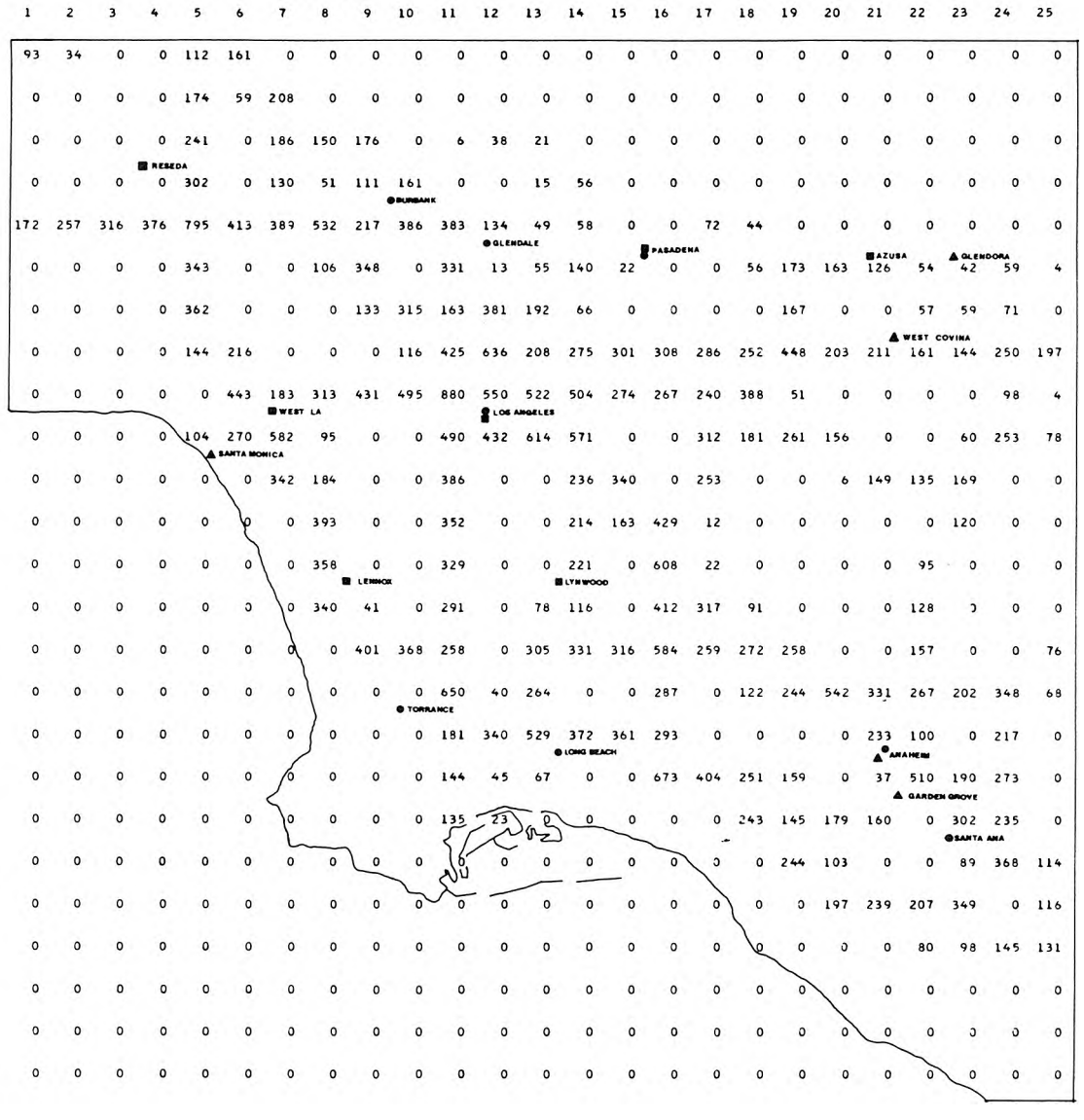

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 93 | 34 | 0 | 0 | 136 | 173 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 186 | 62 | 208 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 248 | 0 | 185 | 146 | 168 | 0 | 6 | 38 | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0 | 0 | 306 | 0 | 130 | 51 | 104 | 153 | 0 | 0 | 15 | 56 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 148 | 248 | 310 | 377 | 801 | 420 | 400 | 540 | 223 | 388 | 377 | 127 | 49 | 64 | 0 | 0 | 75 | 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 343 | 0 | 0 | 106 | 348 | 0 | 324 | 13 | 56 | 144 | 23 | 0 | 0 | 58 | 184 | 172 | 127 | 54 | 40 | 58 | 4 |
| 19 | 0 | 0 | 0 | 0 | 362 | 0 | 0 | 0 | 133 | 316 | 160 | 377 | 202 | 68 | 0 | 0 | 0 | 0 | 179 | 0 | 0 | 61 | 57 | 71 | 0 |
| 18 | 0 | 0 | 0 | 0 | 144 | 217 | 0 | 0 | 0 | 118 | 445 | 651 | 209 | 277 | 301 | 308 | 286 | 252 | 460 | 213 | 222 | 176 | 156 | 261 | 213 |
| 17 | 0 | 0 | 0 | 0 | 0 | 450 | 190 | 324 | 443 | 507 | 885 | 550 | 528 | 501 | 274 | 267 | 240 | 387 | 51 | 0 | 0 | 0 | 0 | 91 | 4 |
| 16 | 0 | 0 | 0 | 0 | 109 | 280 | 597 | 99 | 0 | 0 | 492 | 432 | 617 | 589 | 0 | 0 | 305 | 177 | 249 | 147 | 0 | 0 | 56 | 236 | 70 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 317 | 189 | 0 | 0 | 386 | 0 | 0 | 271 | 340 | 0 | 243 | 0 | 0 | 6 | 140 | 125 | 158 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 427 | 0 | 0 | 352 | 0 | 0 | 245 | 163 | 418 | 12 | 0 | 0 | 0 | 0 | 0 | 114 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 373 | 0 | 0 | 332 | 0 | 0 | 249 | 0 | 589 | 22 | 0 | 0 | 0 | 0 | 93 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 351 | 42 | 0 | 297 | 0 | 87 | 130 | 0 | 383 | 317 | 91 | 0 | 0 | 0 | 125 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 414 | 380 | 268 | 0 | 327 | 326 | 310 | 553 | 262 | 272 | 258 | 0 | 0 | 156 | 0 | 0 | 77 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 678 | 41 | 278 | 0 | 0 | 264 | 0 | 123 | 239 | 528 | 318 | 231 | 167 | 293 | 66 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 173 | 356 | 550 | 380 | 362 | 256 | 0 | 0 | 0 | 0 | 224 | 97 | 0 | 165 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 141 | 45 | 67 | 0 | 0 | 644 | 404 | 246 | 151 | 0 | 36 | 482 | 184 | 235 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 134 | 23 | 0 | 0 | 0 | 0 | 0 | 243 | 142 | 171 | 150 | 0 | 296 | 210 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 238 | 100 | 0 | 0 | 78 | 354 | 119 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 187 | 225 | 183 | 313 | 0 | 124 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 80 | 95 | 139 | 126 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

TOTAL VMT/DAY IN 1973 = 49343. IN THOUSANDS OF VMT PER DAY

FIGURE A2.32

FREEWAY TRAFFIC COUNTS FOR 1974 IN THOUSANDS OF VMT PER DAY (PRESENT STUDY)

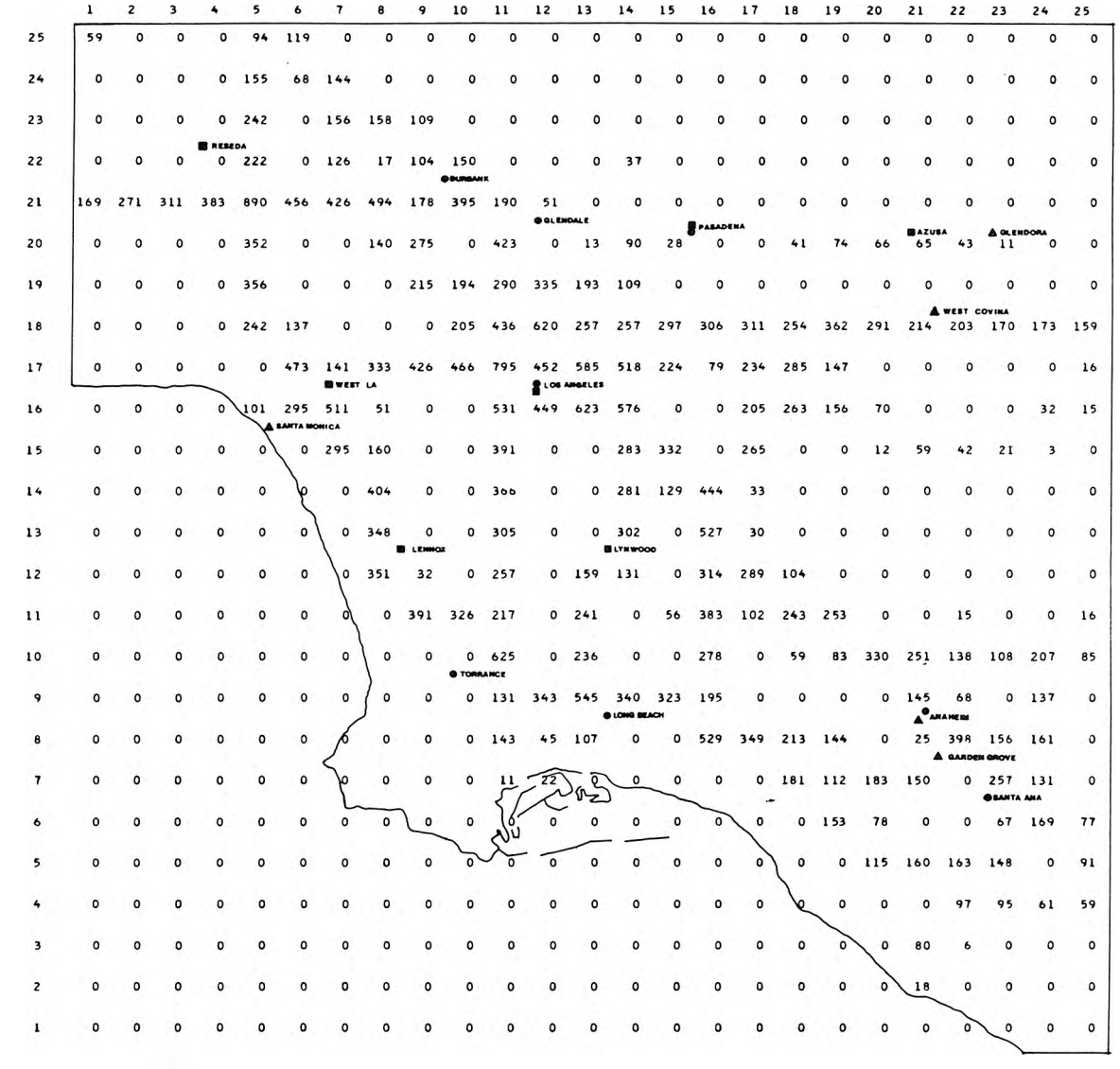
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 93 | 34 | 0 | 0 | 112 | 161 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 174 | 59 | 208 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 241 | 0 | 186 | 150 | 176 | 0 | 6 | 38 | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0 | 0 | 302 | 0 | 130 | 51 | 111 | 161 | 0 | 0 | 15 | 56 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 172 | 257 | 316 | 376 | 795 | 413 | 389 | 532 | 217 | 386 | 383 | 134 | 49 | 58 | 0 | 0 | 72 | 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 343 | 0 | 0 | 106 | 348 | 0 | 331 | 13 | 55 | 140 | 22 | 0 | 0 | 56 | 173 | 163 | 126 | 54 | 42 | 59 | 4 |
| 19 | 0 | 0 | 0 | 0 | 362 | 0 | 0 | 0 | 133 | 315 | 163 | 381 | 192 | 66 | 0 | 0 | 0 | 0 | 167 | 0 | 0 | 57 | 59 | 71 | 0 |
| 18 | 0 | 0 | 0 | 0 | 144 | 216 | 0 | 0 | 0 | 116 | 425 | 636 | 208 | 275 | 301 | 308 | 286 | 252 | 448 | 203 | 211 | 161 | 144 | 250 | 197 |
| 17 | 0 | 0 | 0 | 0 | 0 | 443 | 183 | 313 | 431 | 495 | 880 | 550 | 522 | 504 | 274 | 267 | 240 | 388 | 51 | 0 | 0 | 0 | 0 | 98 | 4 |
| 16 | 0 | 0 | 0 | 0 | 104 | 270 | 582 | 95 | 0 | 0 | 490 | 432 | 614 | 571 | 0 | 0 | 312 | 181 | 261 | 156 | 0 | 0 | 60 | 253 | 78 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 342 | 184 | 0 | 0 | 386 | 0 | 0 | 236 | 340 | 0 | 253 | 0 | 0 | 6 | 149 | 135 | 169 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 393 | 0 | 0 | 352 | 0 | 0 | 214 | 163 | 429 | 12 | 0 | 0 | 0 | 0 | 0 | 120 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 358 | 0 | 0 | 329 | 0 | 0 | 221 | 0 | 608 | 22 | 0 | 0 | 0 | 0 | 95 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 340 | 41 | 0 | 291 | 0 | 78 | 116 | 0 | 412 | 317 | 91 | 0 | 0 | 0 | 128 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 401 | 368 | 258 | 0 | 305 | 331 | 316 | 584 | 259 | 272 | 258 | 0 | 0 | 157 | 0 | 0 | 76 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 650 | 40 | 264 | 0 | 0 | 287 | 0 | 122 | 244 | 542 | 331 | 267 | 202 | 348 | 68 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 181 | 340 | 529 | 372 | 361 | 293 | 0 | 0 | 0 | 0 | 233 | 100 | 0 | 217 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 144 | 45 | 67 | 0 | 0 | 673 | 404 | 251 | 159 | 0 | 37 | 510 | 190 | 273 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 135 | 23 | 0 | 0 | 0 | 0 | 0 | 243 | 145 | 179 | 160 | 0 | 302 | 235 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 244 | 103 | 0 | 0 | 89 | 368 | 114 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 197 | 239 | 207 | 349 | 0 | 116 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 80 | 98 | 145 | 131 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |




TOTAL VMT/DAY IN 1974 = 49523. IN THOUSANDS OF VMT PER DAY

FIGURE A2.33

FREEWAY TRAFFIC COUNTS FOR 1969 IN THOUSANDS OF VMT PER DAY (ROTH ET AL. 1974)




TOTAL VMT/DAY = 41926. IN THOUSANDS OF VMT PER DAY

FIGURE A2.34

there were a few state-maintained divided highways (for example portions of Route 55) which on a map would look as wide as a freeway; which Roth, et al. apparently classified as a freeway even though the State Department of Public Works did not. This difference in the definition of what constitutes a freeway is less important to our traffic counts for 1972 through 1974. This is because most divided highway segments in question were soon upgraded to full freeway status by Cal Trans after necessary grade separations at major intersections were completed to remove cross-traffic conflicts to high speed travel. Our exclusion of non-freeway divided highways from the 1969 freeway traffic inventory is one reason why our traffic count total is 4.3% lower than that of Roth, et al. for that year. Most remaining discrepancies in the traffic counts could be eliminated by a 1/8 mile or less local realignment of grid cell boundaries. Resolution of these small boundary alignment problems was felt to be unnecessary since they result from an area source description of a line source problem in which the grid cell concept artificially obscures each freeway's location by averaging it over a four square mile area anyway.

In a few notable cases, however, no minor realignment of the grid system would successfully explain observed differences in traffic density. The largest disagreement on the map is a difference of 149 thousand VMT daily in square I 16 by J 17. The only freeway in that square is the Pomona Freeway, which completely transects that grid cell while proceeding from west to east (see Roth, et al.'s map, Figure A2.29). That freeway's minimum length in that cell is at

least two miles by definition of the grid dimensions. All segments of that freeway within that square carried in excess of 100,000 vehicles daily in 1969 (California Department of Public Works, 1969), making total vehicle miles traveled necessarily greater than 200,000 VMT daily in that grid square. Roth, et al. show 79,000 VMT daily in that square, while we obtain 228,000 VMT daily. Another large difference in traffic density for which we have yet to find a complete explanation arises at the intersection of the San Diego and Ventura Freeways in square I 5 by J 21. The 131 thousand VMT difference between these two surveys at that point is the third largest on the grid. Roth, et al. indicate that that grid cell contains the heaviest freeway traffic density in the Los Angeles area, while our survey indicates that there is a greater freeway traffic density near the intersection of the Harbor and Santa Monica freeways near downtown Los Angeles. We do not intend to claim that our traffic counts are any better than those of Roth, et al. On the contrary, we feel that their data were carefully prepared or we would not have used Roth, et al.'s surface street traffic counts for 1969 as the basis for our surface street traffic growth study. Undoubtedly, many of the discrepancies between these two traffic surveys represent occasional human errors on both parts. We simply wished to illustrate that the existence of a few rather large discrepancies is the natural result of the complexity of tackling this traffic assignment problem manually and not a reflection of carelessness.

The traffic density maps of Figure A2.30 through A2.33 were thus accepted as a reasonable representation of freeway traffic in

those years. $SO_x$ emissions from light duty vehicle freeway travel were then calculated by the method previously described for surface streets. The resulting emission density map for a typical month in the year 1973 is shown in Figure A2.35.

A2.6.4 Heavy Duty Trucks and Buses - Freeway

$SO_x$ emissions from freeway travel by heavy duty trucks and buses were computed by the same method as previously described for surface street travel by these vehicles. The only difference was to substitute the appropriate proportion of total freeway traffic volumes in place of surface street traffic data. The resulting emission density map for a typical month in 1973 is given in Figure A2.36.

A2.6.5 Airport Operations

$SO_x$ emissions from airport operations were computed for major civilian and military airports within the grid system on the basis of fuel usage. The fuel use inventory technique employed was identical to that described in the Energy Balance section of Appendix A3 to this report; Section A3.4.3.2 - Jet Fuel and Aviation Gasoline Consumption. The only difference was that airports were located geographically on our grid system, and off-grid airports are not shown. Sulfur oxides emissions were computed from fuel use data at each airport on the basis of the fuel sulfur content assumed for jet fuel and aviation gasoline in Table A3.10 of the Sulfur Balance section of Appendix A3 to this report. Total on-grid $SO_x$ emissions from aircraft take-offs and landings are dominated by traffic at Los Angeles International Airport. Estimated $SO_x$ emissions from that airport's traffic averaged


AUTO & LT TRUCK FREEWAY SOX EMISSIONS FOR YEAR 1973 , MONTH 7 IN TONS/DAY AS SO2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
25 0.02 0.01 0.0 0.0 0.02 0.03 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
24 0.0 0.0 0.0 0.0 0.03 0.01 0.04 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
23 0.0 0.0 0.0 0.0 0.05 0.0 0.03 0.03 0.03 0.0 0.00 0.01 0.00 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
22 0.0 0.0 0.0 0.0 0.06 0.0 0.02 0.01 0.02 0.03 0.0 0.0 0.00 0.01 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
21 0.03 0.05 0.06 0.07 0.15 0.08 0.07 0.10 0.04 0.07 0.07 0.02 0.01 0.01 0.0 0.0 0.01 0.01 0.0 0.0 0.0 0.0 0.0 0.0
20 0.0 0.0 0.0 0.0 0.06 0.0 0.0 0.02 0.06 0.0 0.06 0.00 0.01 0.03 0.00 0.0 0.0 0.01 0.03 0.03 0.02 0.01 0.01 0.01 0.00
19 0.0 0.0 0.0 0.0 0.07 0.0 0.0 0.0 0.02 0.06 0.03 0.07 0.04 0.01 0.0 0.0 0.0 0.0 0.03 0.0 0.0 0.01 0.01 0.01 0.0
18 0.0 0.0 0.0 0.0 0.03 0.04 0.0 0.0 0.0 0.02 0.08 0.12 0.04 0.05 0.05 0.06 0.05 0.05 0.08 0.04 0.04 0.03 0.03 0.05 0.04
17 0.0 0.0 0.0 0.0 0.0 0.08 0.03 0.06 0.08 0.09 0.16 0.10 0.10 0.09 0.05 0.05 0.04 0.07 0.01 0.0 0.0 0.0 0.0 0.02 0.00
16 0.0 0.0 0.0 0.0 0.02 0.05 0.11 0.02 0.0 0.0 0.09 0.08 0.11 0.11 0.0 0.0 0.06 0.03 0.05 0.03 0.0 0.0 0.01 0.04 0.01
15 0.0 0.0 0.0 0.0 0.0 0.0 0.06 0.03 0.0 0.0 0.07 0.0 0.0 0.05 0.06 0.0 0.04 0.0 0.0 0.00 0.03 0.02 0.03 0.0 0.0
14 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.08 0.0 0.0 0.06 0.0 0.0 0.04 0.03 0.08 0.00 0.0 0.0 0.0 0.0 0.0 0.02 0.0 0.0
13 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.07 0.0 0.0 0.06 0.0 0.0 0.05 0.0 0.11 0.00 0.0 0.0 0.0 0.0 0.02 0.0 0.0 0.0
12 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.06 0.01 0.0 0.05 0.0 0.02 0.02 0.0 0.07 0.06 0.02 0.0 0.0 0.0 0.02 0.0 0.0 0.0
11 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.08 0.07 0.05 0.0 0.06 0.06 0.06 0.10 0.05 0.05 0.05 0.0 0.0 0.03 0.0 0.0 0.01
10 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.12 0.01 0.05 0.0 0.0 0.05 0.0 0.02 0.04 0.10 0.06 0.04 0.03 0.05 0.01
9 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.03 0.06 0.10 0.07 0.07 0.05 0.0 0.0 0.0 0.0 0.04 0.02 0.0 0.03 0.0
8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.03 0.01 0.01 0.0 0.0 0.12 0.07 0.04 0.03 0.0 0.01 0.09 0.03 0.04 0.0
7 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.02 0.00 0.0 0.0 0.0 0.0 0.0 0.04 0.03 0.03 0.03 0.0 0.05 0.04 0.0
6 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.04 0.02 0.0 0.0 0.01 0.06 0.02
5 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.03 0.04 0.03 0.06 0.0 0.02
4 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.01 0.02 0.03 0.02
3 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
2 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
REBEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
SOX TONS/DAY 8.993
FRACTION AS SO3 0.017

FIGURE A2.35

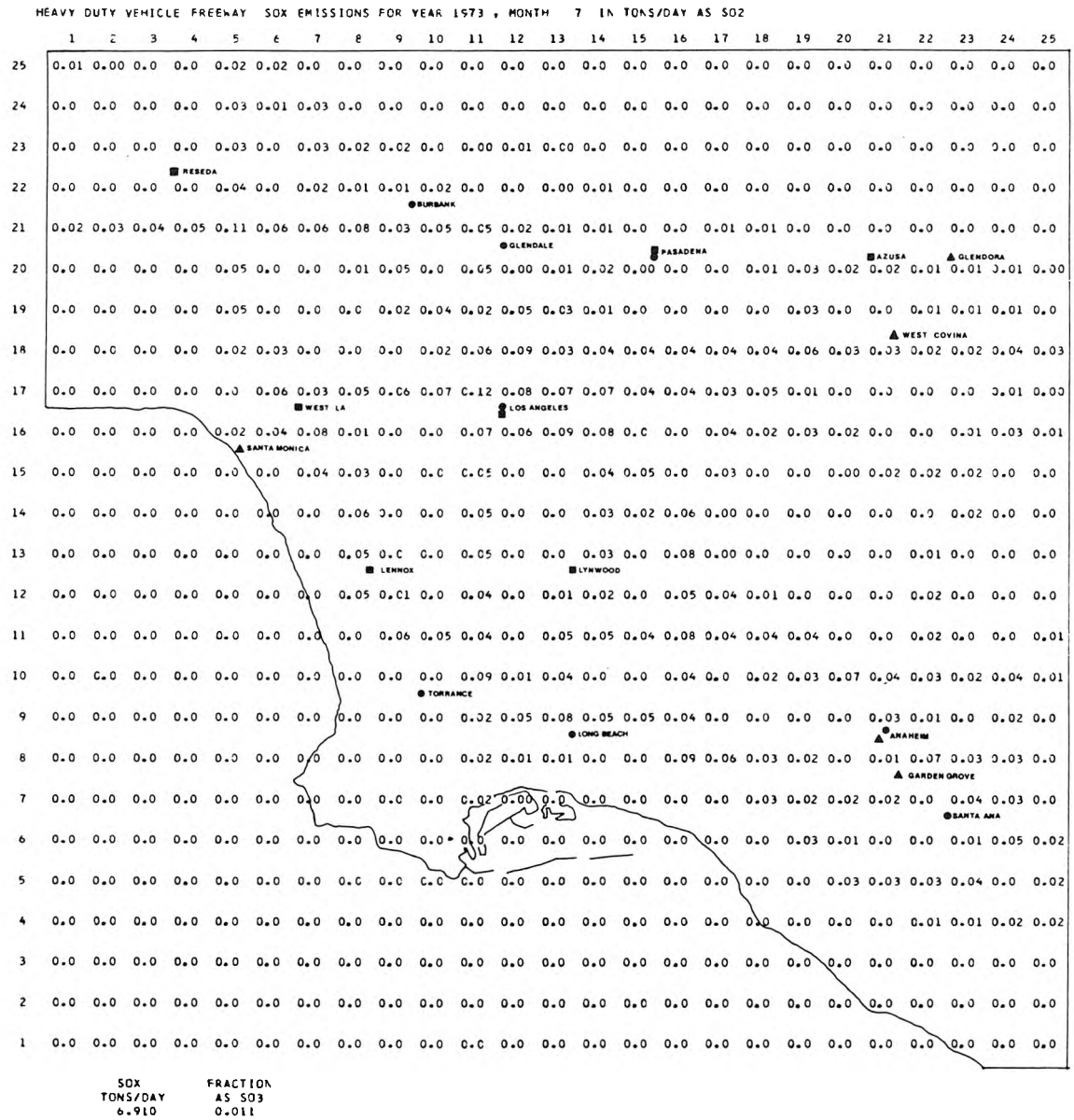

HEAVY DUTY VEHICLE FREEWAY SOX EMISSIONS FOR YEAR 1973 , MONTH 7 IN TONS/DAY AS SO2
RESEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
SOX TONS/DAY 6.910
FRACTION AS SO3 0.011

FIGURE A2.36

0.88 tons per day during 1973 versus total on-grid aircraft take-off and landing emissions of about 1.06 tons per day in that year, as shown in Figure A2.37.

### A2.6.6 Shipping Operations

Fuel oil combustion by ship traffic was inventoried in three parts: dockside operations, fuel use by ships under way in the harbor plus harbor entrance area, and fuel use in shipping lanes at sea which run parallel to the coast. The methodology for computing fuel use for each part of the shipping traffic inventory is described in detail in Appendix A3 to this report; Section A3.4.3.3 - Residual and Distillate Fuel Oil Consumption. Sulfur oxides emissions were calculated from fuel use data using the sulfur content of ship fuel given in Appendix A3: Sulfur Balance, Table A3.10. The spatial distribution of emissions was estimated by drawing the grid system over the NOAA shipping lane map cited in Appendix A3. Total fuel use at dockside locations was apportioned to grid squares in proportion to the length of waterfront dock area in each square. Fuel use by ships under way in the harbor and harbor entrance were apportioned to grid squares by the fraction of the harbor area plus harbor entrance precautionary area falling into each grid square as shown on the NOAA map.

Shipping lanes are shown on the map as having a northbound and southbound track paralleling the coast. These shipping lanes are each several miles in width. Vessel-miles traveled in each track of the shipping lanes were computed from lane-length and ship movement records as described in Appendix A3 to this report. Total emissions

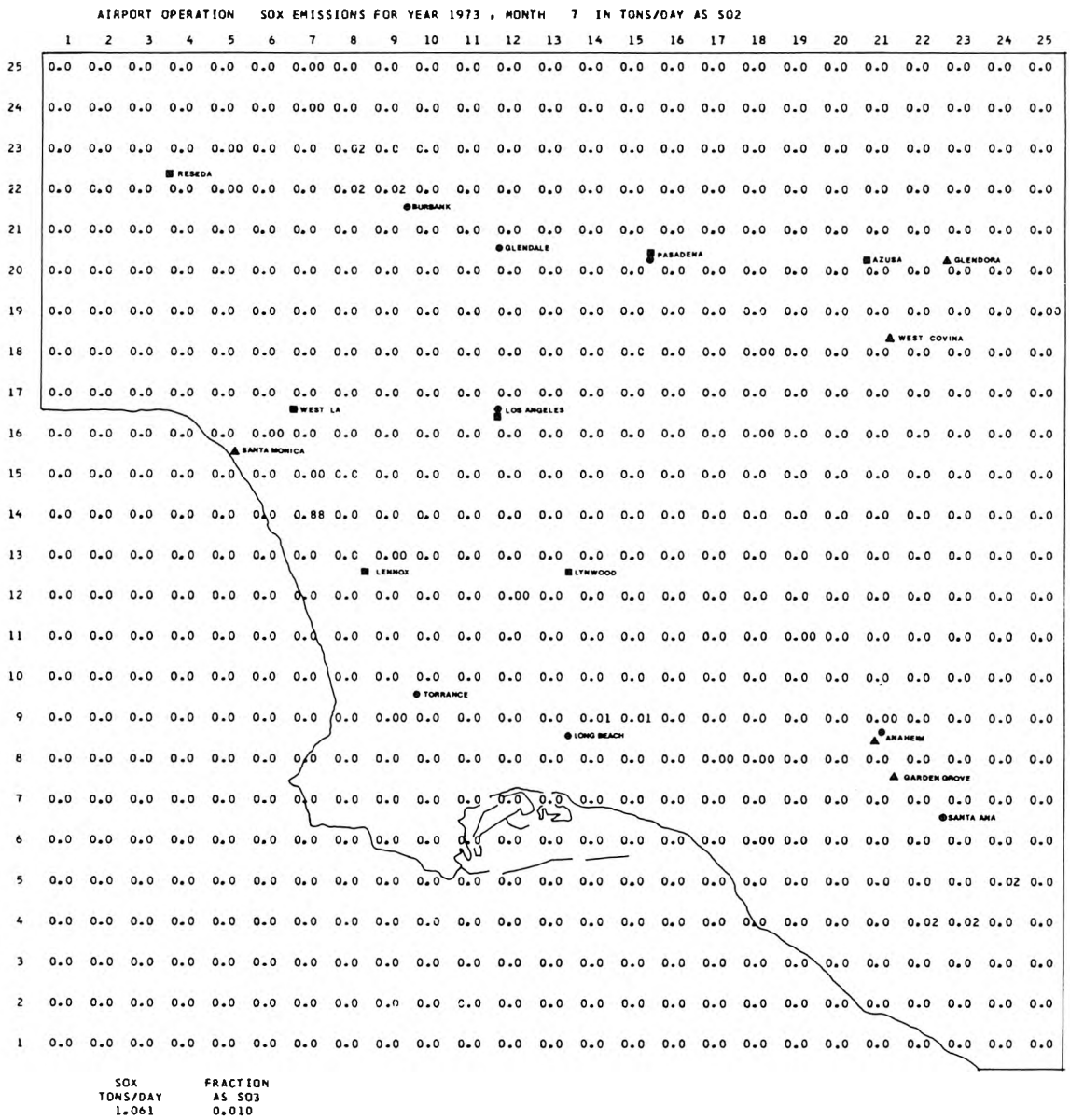

AIRPORT OPERATION SOX EMISSIONS FOR YEAR 1973 , MONTH 7 IN TONS/DAY AS SO2
RESEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
SOX TONS/DAY 1.061
FRACTION AS SO3 0.010

FIGURE A2.37

for each track of the shipping lanes were computed from vessel fuel economy and fuel sulfur content. Finally, the emissions in the shipping lanes were apportioned to the grid system on the basis of the fraction of the area of each shipping lane falling within a given grid square.

Shipping operations $SO_x$ emissions estimates for a month in 1973 are shown in Figure A2.38. Total on-grid shipping emissions are in excess of ten tons per day of $SO_x$, which is greater than annual average fuel burning emissions from harbor area refineries. The reason for the substantial $SO_x$ emission rate from ship traffic is found in the ships' ability to avoid limitations on the sulfur content of their fuel. High sulfur fuel oil which could not be burned legally by a stationary source in the harbor area can be burned in unregulated maritime boilers.

### A2.6.7 Railroad Operations

Railroad operation $SO_x$ emissions were inventoried by procedures outlined in Appendix A3 of this report. The Residual and Distillate Oil Consumption Section A3.4.3.3 of Appendix A3 should be consulted for detailed references on fuel use data. The sulfur content of railroad fuels is given in Appendix A3, Table A3.10.

Briefly, the procedure used to estimate railroad $SO_x$ emissions was as follows. Fuel use by railroads was obtained for the entire state for each year from Bureau of Mines publications. Total California railroad track mileage was obtained from the U.S. Department of Transportation's Federal Railway Administration, and fuel use per

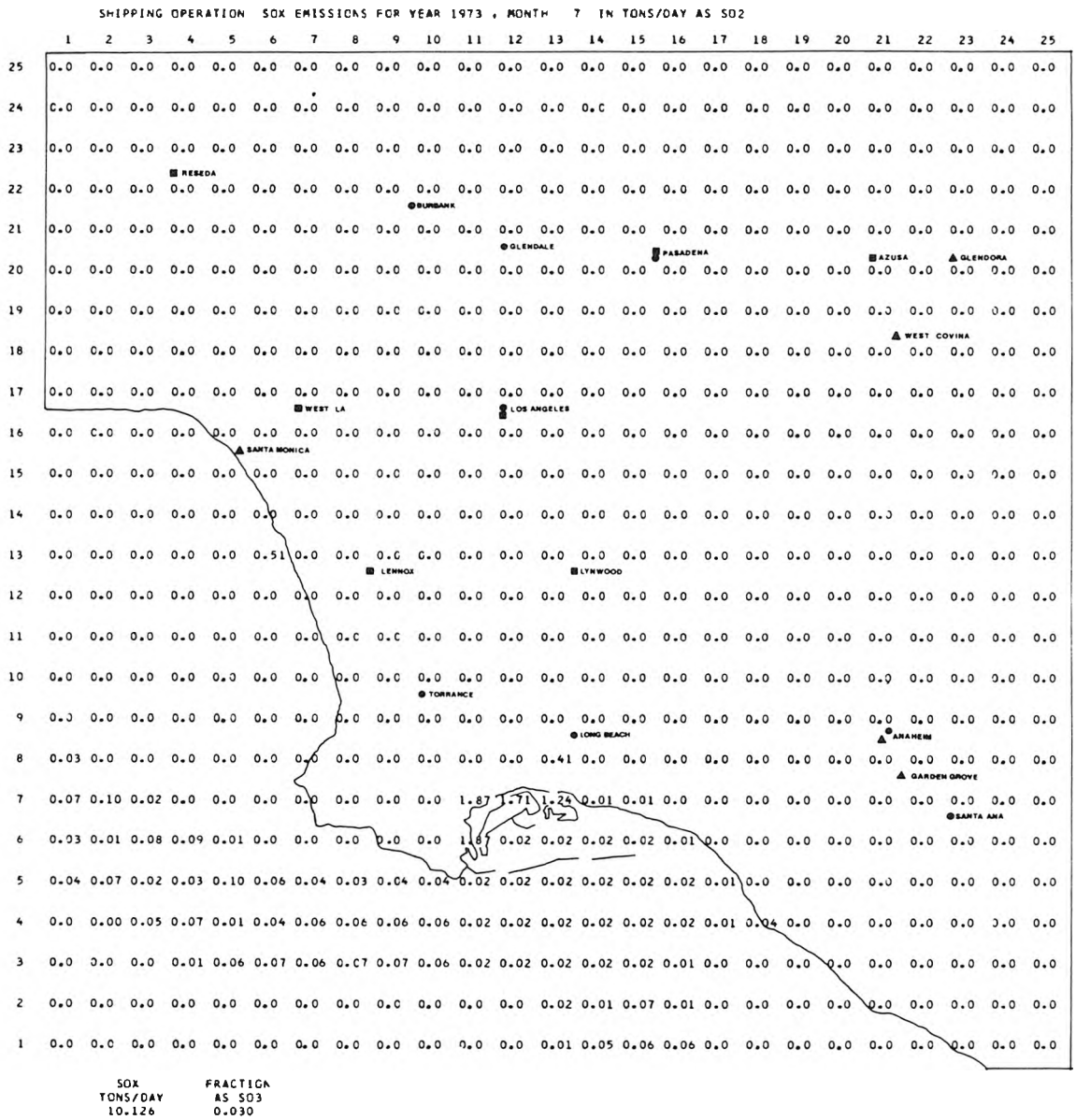

SHIPPING OPERATION SOX EMISSIONS FOR YEAR 1973 , MONTH 7 IN TONS/DAY AS SO2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
25 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
24 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
23 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
22 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
21 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
20 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
19 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
18 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
17 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
16 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
15 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
14 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
13 0.0 0.0 0.0 0.0 0.0 0.51 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
12 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
11 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
10 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
9 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
8 0.03 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.41 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
7 0.07 0.10 0.02 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.87 1.71 1.24 0.01 0.01 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
6 0.03 0.01 0.08 0.09 0.01 0.0 0.0 0.0 0.0 0.0 1.87 0.02 0.02 0.02 0.02 0.01 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
5 0.04 0.07 0.02 0.03 0.10 0.06 0.04 0.03 0.04 0.04 0.02 0.02 0.02 0.02 0.02 0.02 0.01 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
4 0.0 0.00 0.05 0.07 0.01 0.04 0.06 0.06 0.06 0.06 0.02 0.02 0.02 0.02 0.02 0.02 0.01 0.04 0.0 0.0 0.0 0.0 0.0 0.0 0.0
3 0.0 0.0 0.0 0.01 0.06 0.07 0.06 0.07 0.07 0.06 0.02 0.02 0.02 0.02 0.02 0.01 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
2 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.02 0.01 0.07 0.01 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.01 0.05 0.06 0.06 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
REDEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
SOX TONS/DAY 10.126
FRACTION AS SO3 0.030

FIGURE A2.38

average track mile was computed for the state. Then track mileage within each grid square was measured on U. S. Geological Survey 7 1/2" maps. Fuel use per grid square was then estimated by multiplying total track mileage per grid square by fuel use per track mile. Compensation for heavy traffic in railroad yards was attempted by counting all side tracks in the yards as being in active use (admittedly a rather crude guess). Next, the sulfur content of fuel was used to compile total $SO_x$ emissions on a daily average basis. An example $SO_x$ emissions estimate for railroads is shown in Figure A2.39 for a typical month in 1973. Many grid squares contain non-zero $SO_x$ emissions of less than .01 tons per day and thus do not show any significant emissions on that map. Occupied squares of that type are indicated as "0.00" while track-less grid cells are given as "0.0".

A2.6.8 Mobile Source Emissions in Time Series

In order to view mobile source emissions in time series, seasonal changes in fuel sales have been combined with fluctuations in fuel sulfur content and traffic volume growth. The $SO_x$ emissions from gasoline use seem nearly level over our three year study period, as shown in Figure A2.40. $SO_x$ emissions from ships, railroads, aircraft and heavy duty vehicles are likewise nearly constant over time as seen in Figure A2.41.

But while automotive emissions seem nearly constant over time on a seasonal basis, there is still a strong diurnal variation in hourly traffic volumes. As seen in Figure A2.42, motor vehicle traffic peaks twice daily (at morning and evening rush hours).

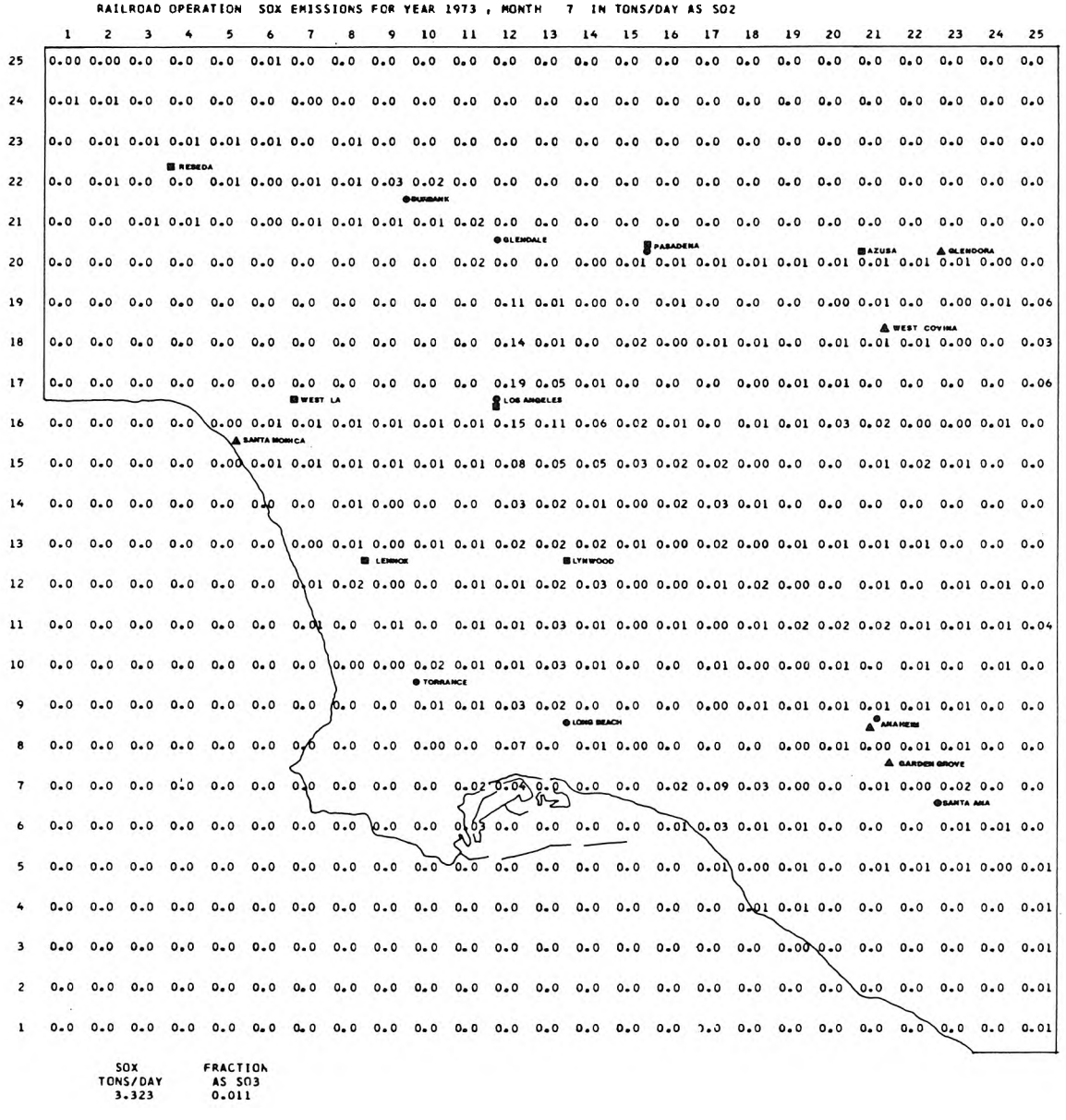

RAILROAD OPERATION SOX EMISSIONS FOR YEAR 1973 , MONTH 7 IN TONS/DAY AS SO2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
25 0.00 0.00 0.0 0.0 0.0 0.01 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
24 0.01 0.01 0.0 0.0 0.0 0.0 0.00 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
23 0.0 0.01 0.01 0.01 0.01 0.01 0.0 0.01 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
22 0.0 0.01 0.0 0.0 0.01 0.00 0.01 0.01 0.03 0.02 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
21 0.0 0.0 0.01 0.01 0.0 0.00 0.01 0.01 0.01 0.01 0.02 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
20 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.02 0.0 0.0 0.00 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.00 0.0
19 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.11 0.01 0.00 0.0 0.01 0.0 0.0 0.0 0.00 0.01 0.0 0.00 0.01 0.06
18 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.14 0.01 0.0 0.02 0.00 0.01 0.01 0.0 0.01 0.01 0.01 0.00 0.0 0.03
17 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.19 0.05 0.01 0.0 0.0 0.0 0.00 0.01 0.01 0.0 0.0 0.0 0.0 0.06
16 0.0 0.0 0.0 0.0 0.00 0.01 0.01 0.01 0.01 0.01 0.01 0.15 0.11 0.06 0.02 0.01 0.0 0.01 0.01 0.03 0.02 0.00 0.00 0.01 0.0
15 0.0 0.0 0.0 0.0 0.00 0.01 0.01 0.01 0.01 0.01 0.01 0.08 0.05 0.05 0.03 0.02 0.02 0.00 0.0 0.0 0.01 0.02 0.01 0.0 0.0
14 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.01 0.00 0.0 0.0 0.03 0.02 0.01 0.00 0.02 0.03 0.01 0.0 0.0 0.0 0.0 0.0 0.0 0.0
13 0.0 0.0 0.0 0.0 0.0 0.0 0.00 0.01 0.00 0.01 0.01 0.02 0.02 0.02 0.01 0.00 0.02 0.00 0.01 0.01 0.01 0.01 0.0 0.0 0.0
12 0.0 0.0 0.0 0.0 0.0 0.0 0.01 0.02 0.00 0.0 0.01 0.01 0.02 0.03 0.00 0.00 0.01 0.02 0.00 0.0 0.01 0.0 0.01 0.01 0.0
11 0.0 0.0 0.0 0.0 0.0 0.0 0.01 0.0 0.01 0.0 0.01 0.01 0.03 0.01 0.00 0.01 0.00 0.01 0.02 0.02 0.02 0.01 0.01 0.01 0.04
10 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.00 0.00 0.02 0.01 0.01 0.03 0.01 0.0 0.0 0.01 0.00 0.00 0.01 0.0 0.01 0.0 0.01 0.0
9 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.01 0.01 0.03 0.02 0.0 0.0 0.0 0.00 0.01 0.01 0.01 0.01 0.01 0.01 0.0 0.0
8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.00 0.0 0.07 0.0 0.01 0.00 0.0 0.0 0.0 0.00 0.01 0.00 0.01 0.01 0.0 0.0
7 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.02 0.04 0.0 0.0 0.0 0.02 0.09 0.03 0.00 0.0 0.01 0.00 0.02 0.0 0.0
6 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.03 0.0 0.0 0.0 0.0 0.01 0.03 0.01 0.01 0.0 0.0 0.0 0.01 0.01 0.0
5 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.01 0.00 0.01 0.0 0.01 0.01 0.01 0.00 0.01
4 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.01 0.01 0.0 0.0 0.0 0.0 0.0 0.01
3 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.00 0.0 0.0 0.0 0.0 0.0 0.01
2 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.01
1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.01
REDEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
SOX TONS/DAY 3.323
FRACTION AS SO3 0.011

FIGURE A2.39

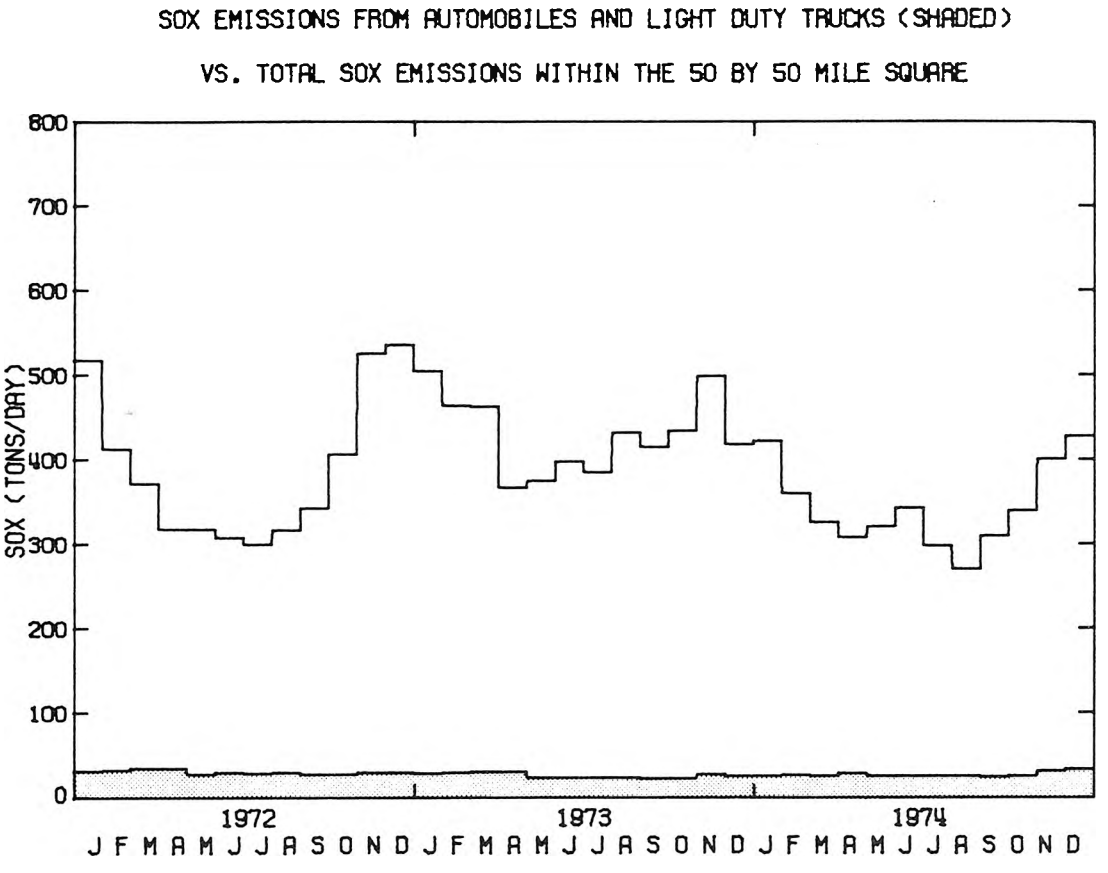

SOX EMISSIONS FROM AUTOMOBILES AND LIGHT DUTY TRUCKS (SHADED)
VS. TOTAL SOX EMISSIONS WITHIN THE 50 BY 50 MILE SQUARE
SOX (TONS/DAY)
800
700
600
500
400
300
200
100
0
1972
1973
1974
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

FIGURE A2.40

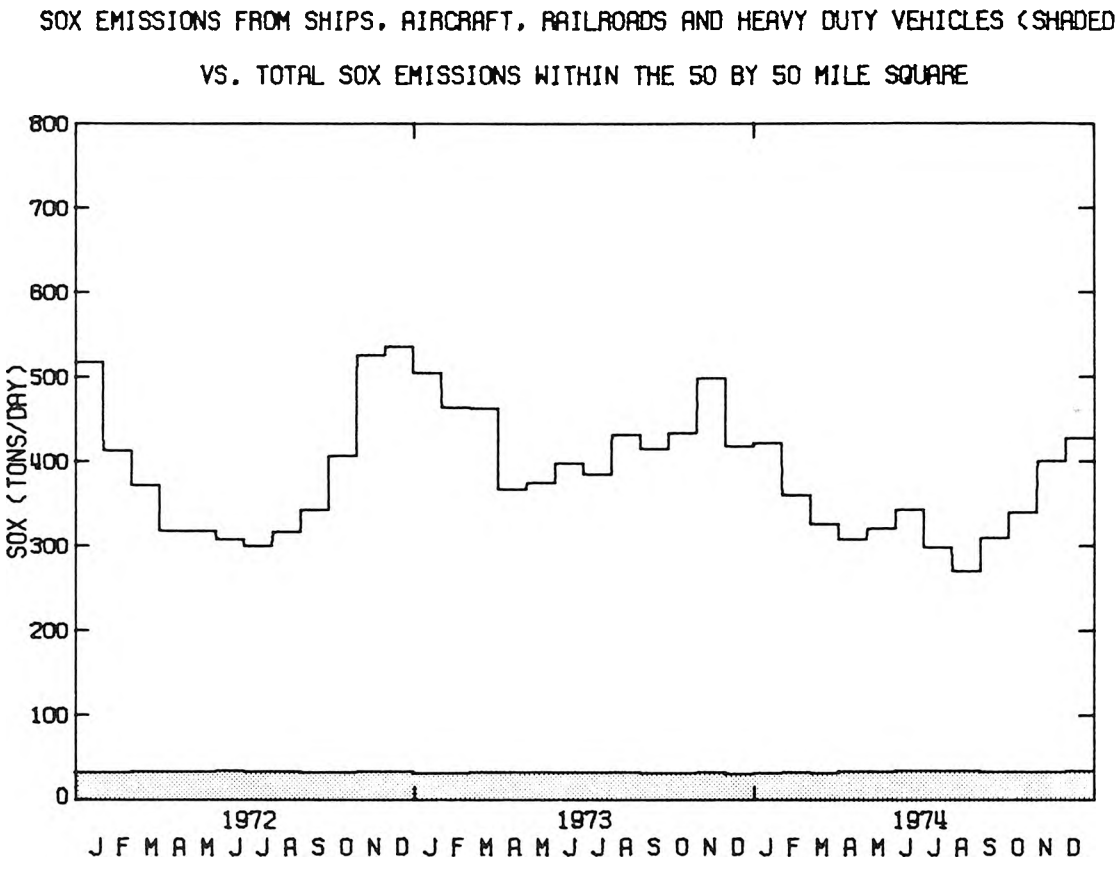

SOX EMISSIONS FROM SHIPS, AIRCRAFT, RAILROADS AND HEAVY DUTY VEHICLES (SHADED)
VS. TOTAL SOX EMISSIONS WITHIN THE 50 BY 50 MILE SQUARE
SOX (TONS/DAY)
800
700
600
500
400
300
200
100
0
1972
1973
1974
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

FIGURE A2.41

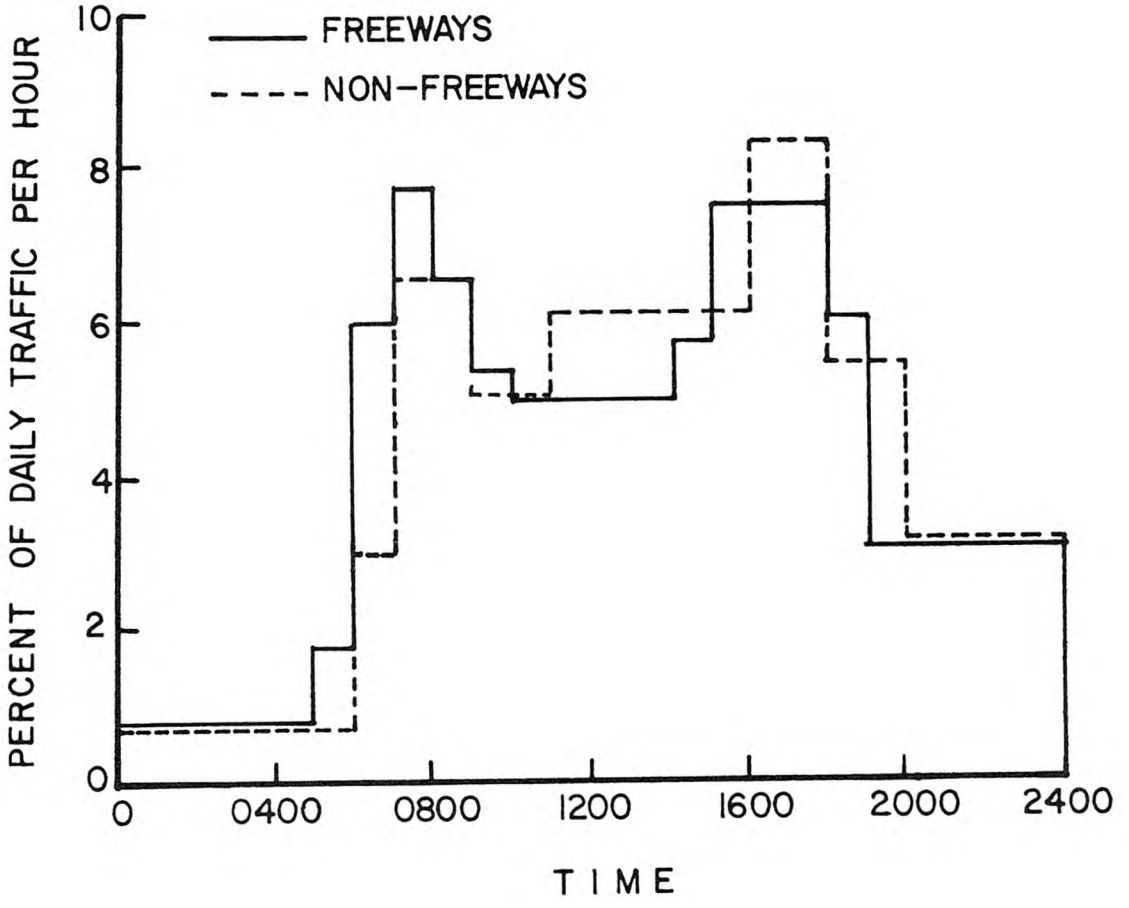



FIGURE A2.42

Diurnal Variation of Los Angeles Traffic Flow
(from Nordsieck, 1974)

## A2.7 Emission Inventory Summary and Discussion

Figure A2.43 summarizes sulfur oxides emissions within the 50 by 50 mile square for the years 1972 through 1974. From Figure A2.43 we note that the majority of sulfur oxides emissions arise from combustion-related sources, both stationary and mobile. Electric utility fuel combustion was the largest single $SO_x$ emission source category during 1974. This represents a substantial change since 1972 when sulfur recovery and sulfuric acid plants in the chemical plant category constituted the largest group of $SO_x$ sources on an annual average basis. This shift in relative source contributions is attributed mainly to the installation of tail gas clean-up equipment at Los Angeles County chemical plants, combined with increased oil burning at power plants due to natural gas curtailment.

A second major shift in relative source contributions is seen to be seasonal in nature. Power plants historically have emitted greater quantities of $SO_x$ during the winter months. From Figure A2.43, one might quickly assume that electricity demand is vastly higher in the winter months than in the summer, but that conclusion would be wrong. Energy use within the 50 by 50 mile square grid is detailed in Figure A2.44 from information gathered while compiling Appendices A2 and A3 to this study. Total monthly electricity use within that study area is fairly constant throughout the year. Instead, what has happened is that residential, commercial and industrial demands for fossil fuel rise sharply during the winter. These customers have a higher priority for receiving service from the relatively fixed supply of natural gas available throughout the year than do the

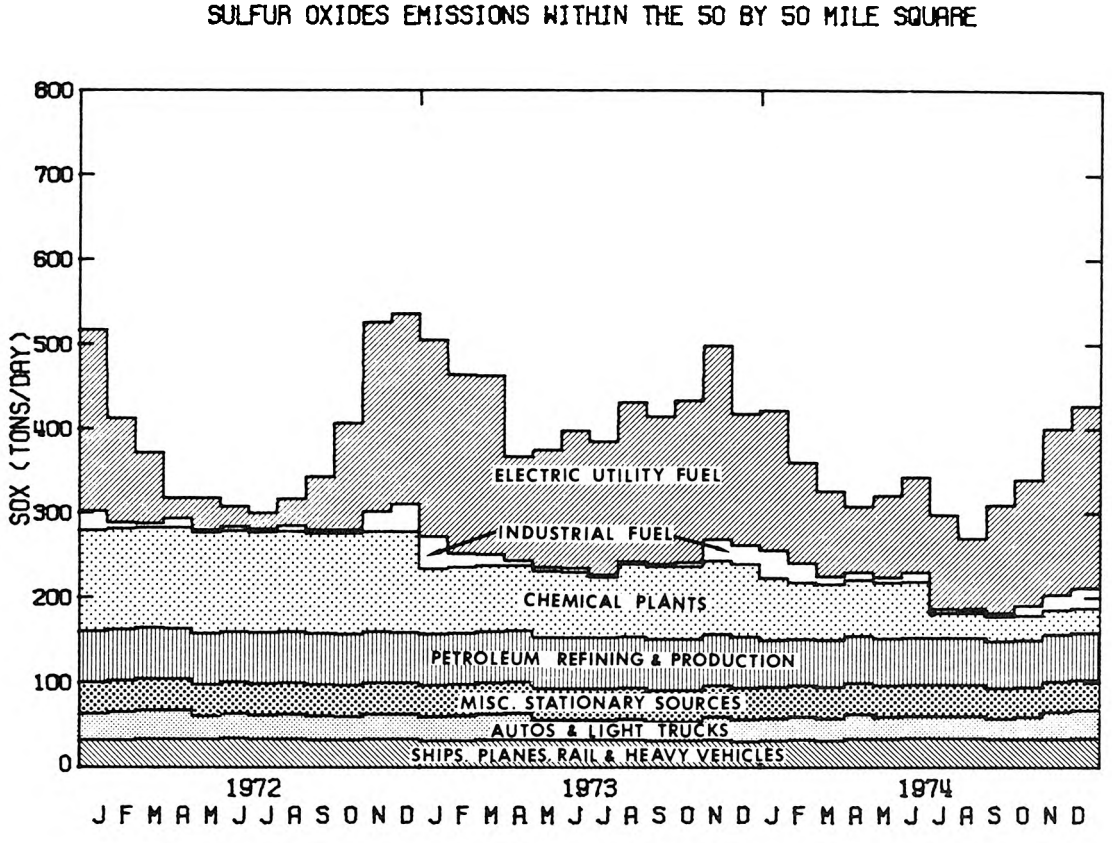

SULFUR OXIDES EMISSIONS WITHIN THE 50 BY 50 MILE SQUARE
SOX (TONS/DAY)
800
700
600
500
400
300
200
100
0
ELECTRIC UTILITY FUEL
INDUSTRIAL FUEL
CHEMICAL PLANTS
PETROLEUM REFINING & PRODUCTION
MISC. STATIONARY SOURCES
AUTOS & LIGHT TRUCKS
SHIPS, PLANES, RAIL & HEAVY VEHICLES
1972
1973
1974
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

FIGURE A2.43

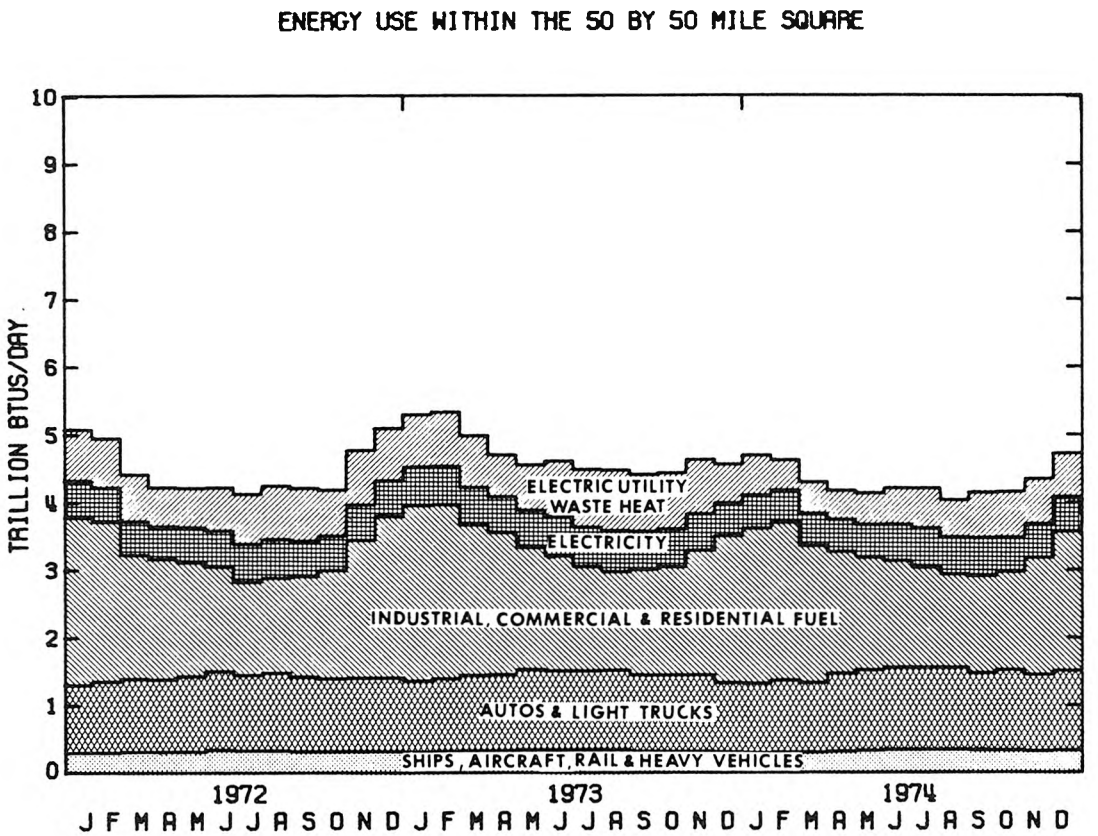

ENERGY USE WITHIN THE 50 BY 50 MILE SQUARE
TRILLION BTUS/DAY
10
9
8
7
6
5
4
3
2
1
0
ELECTRIC UTILITY WASTE HEAT
ELECTRICITY
INDUSTRIAL, COMMERCIAL & RESIDENTIAL FUEL
AUTOS & LIGHT TRUCKS
SHIPS, AIRCRAFT, RAIL & HEAVY VEHICLES
1972
1973
1974
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

FIGURE A2.44

basin's electric utilities. The result is that the gas supply to utilities and some large industries has been curtailed during winter months, with an attendant substitution of sulfur-bearing fuel oils for natural gas by those customers. These major shifts in source emission strength from month to month will provide a tough test for any air quality model validation effort. This is particularly true for a sulfate air quality modeling study since sulfate concentration seasonal trends tend to buck the $SO_x$ emissions history shown here: Los Angeles sulfate concentrations generally peak in the summer months (for example, see Chapter 2).

It would be tempting to refer to these emission patterns as winter emissions and summer emissions, respectively. That may be misleading however, since only the availability of natural gas during the summer has prevented the higher emission pattern from appearing in the summer season. In fact, as can be seen in Figure A2.43, total $SO_x$ emissions for August 1973 were as high as any winter period of the year 1974. By the year 1979 or 1980, natural gas supplies to electric utilities and large industries in Southern California are expected to be completely curtailed in all months of the year (1975 California Gas Report). The implication is that, in the absence of changes in 1974 emission control regulations, the summertime trough in electric utility $SO_x$ emissions would be "filled in" to about the level of past winter emissions peaks. $SO_x$ from industrial fuel burning would rise substantially.

Tables A2.14 through A2.16 show the monthly emissions history for individual source and equipment types within the general source

# TABLE A2.14a

1972 Sulfur Oxides Emissions Within the 50 by 50 Mile Square Grid
(in short tons per day as $SO_2$)

| STATIONARY SOURCES | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel Combustion | | | | | | | | | | | | | |
| Electric Utilities | 214.86 | 123.46 | 83.56 | 23.90 | 38.33 | 23.98 | 18.54 | 32.22 | 62.40 | 126.81 | 223.96 | 225.17 | 99.81 |
| Refinery Fuel | 17.69 | 5.78 | 3.66 | 9.55 | 2.50 | 3.62 | 3.42 | 5.86 | 3.38 | 3.85 | 20.95 | 19.69 | 8.33 |
| Other Interruptible Gas Customers | 5.56 | 1.37 | 0.61 | 0.75 | 0.64 | 0.67 | 0.39 | 0.63 | 0.51 | 0.59 | 2.74 | 13.29 | 2.33 |
| Firm Gas Customers | 0.46 | 0.43 | 0.29 | 0.27 | 0.24 | 0.20 | 0.17 | 0.15 | 0.16 | 0.18 | 0.30 | 0.40 | 0.27 |
| Chemical Plants | | | | | | | | | | | | | |
| Sulfur Recovery | 93.53 | 93.53 | 93.53 | 93.53 | 93.53 | 93.53 | 93.53 | 93.53 | 93.53 | 93.53 | 93.53 | 93.53 | 93.53 |
| Sulfuric Acid | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 | 25.00 |
| Other Chemicals | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |
| Petroleum Refining and Production | | | | | | | | | | | | | |
| Fluid Catalytic Crackers | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 |
| Sour Water Strippers | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| Delayed Cokers | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 |
| Misc. Refinery Process | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 |
| Oil Field Production | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| Misc. Stationary Sources | | | | | | | | | | | | | |
| Petroleum Coke Kilns | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 |
| Glass Furnaces | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Metals Industries | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 |
| Mineral Products | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sewage Treatment Digesters | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 |
| Other Industrial Processes | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Permitted Incinerators | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| MOBILE SOURCES | | | | | | | | | | | | | |
| Autos and Lt. Trucks-Surface | 19.43 | 20.25 | 21.14 | 20.98 | 17.04 | 18.00 | 17.27 | 17.81 | 16.97 | 16.70 | 18.07 | 17.93 | 18.46 |
| Autos and Lt. Trucks-Freeway | 12.21 | 12.72 | 13.28 | 13.18 | 10.70 | 11.31 | 10.85 | 11.91 | 10.66 | 10.49 | 11.35 | 11.26 | 11.60 |
| Heavy Duty Vehicles-Surface | 9.71 | 10.14 | 10.44 | 10.35 | 10.29 | 10.85 | 10.40 | 10.68 | 10.17 | 10.00 | 10.25 | 10.20 | 10.29 |
| Heavy Duty Vehicles-Freeway | 6.10 | 6.37 | 6.56 | 6.50 | 6.46 | 6.81 | 6.53 | 6.71 | 6.39 | 6.28 | 6.44 | 6.41 | 6.46 |
| Airport Operations | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 |
| Shipping Operations | 11.89 | 11.89 | 11.89 | 11.89 | 11.89 | 11.89 | 11.89 | 11.89 | 11.89 | 11.89 | 11.89 | 11.89 | 11.89 |
| Railroad Operations | 3.39 | 3.39 | 3.39 | 3.39 | 3.39 | 3.39 | 3.39 | 3.39 | 3.39 | 3.39 | 3.39 | 3.39 | 3.39 |
| TOTAL | 517.60 | 412.10 | 371.12 | 317.06 | 317.78 | 307.02 | 299.15 | 317.55 | 342.22 | 406.48 | 525.64 | 535.93 | 389.13 |

## TABLE A2.14b

Major Off-Grid Emission Sources Included within the 1972 South Coast Air Basin Sulfur Oxides Modeling Inventory
(in short tons per day as $SO_2$)

| STATIONARY SOURCES | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel Combustion | | | | | | | | | | | | | |
| Electric Utilities | 55.74 | 24.32 | 16.79 | 6.75 | 9.99 | 6.01 | 9.52 | 10.52 | 19.56 | 29.19 | 58.04 | 63.68 | 25.89 |
| Refinery Fuel | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Other Interruptible Gas Customers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Firm Gas Customers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Chemical Plants | | | | | | | | | | | | | |
| Sulfur Recovery | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sulfuric Acid | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Other Chemicals | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Petroleum Refining and Production | | | | | | | | | | | | | |
| Fluid Catalytic Crackers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sour Water Strippers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Delayed Cokers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Misc. Refinery Processes | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Oil Field Production | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Misc. Stationary Sources | | | | | | | | | | | | | |
| Petroleum Coke Kilns | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Glass Furnaces | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 |
| Metals Industries | 35.20 | 35.20 | 35.20 | 35.20 | 35.20 | 35.20 | 35.20 | 35.20 | 35.20 | 35.20 | 35.20 | 35.20 | 35.20 |
| Mineral Products | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 |
| Sewage Treatment Digesters | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Other Industrial Processes | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Permitted Incinerators | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TOTAL | 93.47 | 62.05 | 54.52 | 44.48 | 47.72 | 43.74 | 47.25 | 48.25 | 57.29 | 66.92 | 95.77 | 101.41 | 63.62 |

# TABLE A2.15a

1973 Sulfur Oxides Emissions Within the 50 by 50 Mile Square Grid
(in short tons per day as $SO_2$)

| STATIONARY SOURCES | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel Combustion | | | | | | | | | | | | | |
| Electric Utilities | 232.77 | 212.31 | 212.13 | 123.36 | 139.48 | 163.87 | 157.77 | 189.23 | 174.16 | 192.05 | 229.72 | 155.48 | 181.71 |
| Refinery Fuel | 25.07 | 13.50 | 10.61 | 4.26 | 3.99 | 3.73 | 2.91 | 2.14 | 2.37 | 4.01 | 21.69 | 18.96 | 9.42 |
| Other Interruptible Gas Customers | 12.78 | 2.24 | 2.07 | 0.98 | 0.81 | 0.39 | 0.39 | 0.40 | 0.43 | 0.76 | 3.58 | 2.57 | 2.29 |
| Firm Gas Customers | 0.46 | 0.46 | 0.37 | 0.33 | 0.26 | 0.21 | 0.17 | 0.16 | 0.19 | 0.20 | 0.26 | 0.36 | 0.29 |
| Chemical Plants | | | | | | | | | | | | | |
| Sulfur Recovery | 57.18 | 57.18 | 57.18 | 57.18 | 57.08 | 57.08 | 50.70 | 66.20 | 66.20 | 66.20 | 66.20 | 66.20 | 60.40 |
| Sulfuric Acid | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 |
| Other Chemicals | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |
| Petroleum Refining and Production | | | | | | | | | | | | | |
| Fluid Catalytic Crackers | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 | 52.07 |
| Sour Water Strippers | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| Delayed Cokers | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 |
| Misc. Refinery Process | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 |
| Oil Field Production | 4.50 | 4.50 | 4.50 | 4.50 | 4.50 | 4.50 | 4.50 | 4.50 | 4.50 | 4.50 | 4.50 | 4.50 | 4.50 |
| Misc. Stationary Sources | | | | | | | | | | | | | |
| Petroleum Coke Kilns | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 |
| Glass Furnaces | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Metals Industries | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 | 8.78 |
| Mineral Products | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sewage Treatment Digesters | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 |
| Other Industrial Processes | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Permitted Incinerators | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| MOBILE SOURCES | | | | | | | | | | | | | |
| Autos and Lt. Trucks-Surface | 17.17 | 17.75 | 18.56 | 18.76 | 14.27 | 14.15 | 14.05 | 14.36 | 13.51 | 13.51 | 16.95 | 15.70 | 15.71 |
| Autos and Lt. Trucks-Freeway | 10.98 | 11.35 | 11.87 | 12.01 | 9.13 | 9.05 | 8.99 | 9.19 | 8.64 | 8.64 | 10.85 | 10.05 | 10.05 |
| Heavy Duty Vehicles-Surface | 10.18 | 10.50 | 10.94 | 11.05 | 10.99 | 10.88 | 10.80 | 10.99 | 10.35 | 10.34 | 10.71 | 9.90 | 10.64 |
| Heavy Duty Vehicles-Freeway | 6.51 | 6.72 | 7.00 | 7.07 | 7.03 | 6.96 | 6.91 | 7.03 | 6.62 | 6.61 | 6.85 | 6.33 | 6.80 |
| Airport Operations | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 |
| Shipping Operations | 10.13 | 10.13 | 10.13 | 10.13 | 10.13 | 10.13 | 10.13 | 10.13 | 10.13 | 10.13 | 10.13 | 10.13 | 10.13 |
| Railroad Operations | 3.32 | 3.32 | 3.32 | 3.32 | 3.32 | 3.32 | 3.32 | 3.32 | 3.32 | 3.32 | 3.32 | 3.32 | 3.32 |
| TOTAL | 504.73 | 463.64 | 462.36 | 366.63 | 374.67 | 397.95 | 384.27 | 431.33 | 414.10 | 433.95 | 498.44 | 417.18 | 428.94 |

## TABLE A2.15b

Major Off-Grid Emission Sources Included within the 1973 South Coast Air Basin Sulfur Oxides Modeling Inventory
(in short tons per day as $SO_2$)

| STATIONARY SOURCES | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel Combustion | | | | | | | | | | | | | |
| Electric Utilities | 60.19 | 45.46 | 57.94 | 39.18 | 53.62 | 64.68 | 54.07 | 58.97 | 45.38 | 59.69 | 91.75 | 66.46 | 58.20 |
| Refinery Fuel | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Other Interruptible Gas Customers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Firm Gas Customers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Chemical Plants | | | | | | | | | | | | | |
| Sulfur Recovery | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sulfuric Acid | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Other Chemicals | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Petroleum Refining and Production | | | | | | | | | | | | | |
| Fluid Catalytic Crackers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sour Water Strippers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Delayed Cokers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Misc. Refinery Processes | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Oil Field Production | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Misc. Stationary Sources | | | | | | | | | | | | | |
| Petroleum Coke Kilns | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Glass Furnaces | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 |
| Metals Industries | 41.46 | 41.46 | 41.46 | 41.46 | 41.46 | 41.46 | 41.46 | 41.46 | 41.46 | 41.46 | 41.46 | 41.46 | 41.46 |
| Mineral Products | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 |
| Sewage Treatment Digesters | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Other Industrial Processes | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Permitted Incinerators | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TOTAL | 103.78 | 89.05 | 101.53 | 82.77 | 97.21 | 108.27 | 97.66 | 102.56 | 88.97 | 103.28 | 135.34 | 110.05 | 101.79 |

## TABLE A2.16a

1974 Sulfur Oxides Emissions Within the 50 by 50 Mile Square Grid
(in short tons per day as $SO_2$)

| STATIONARY SOURCES | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel Combustion | | | | | | | | | | | | | |
| Electric Utilities | 166.24 | 119.19 | 101.05 | 77.73 | 97.16 | 113.19 | 111.03 | 84.23 | 127.98 | 148.83 | 197.60 | 215.11 | 130.04 |
| Refinery Fuel | 23.69 | 20.91 | 7.61 | 7.59 | 5.18 | 9.27 | 4.35 | 3.22 | 3.78 | 10.44 | 15.53 | 20.32 | 10.93 |
| Other Interruptible Gas Customers | 8.30 | 1.61 | 0.94 | 0.71 | 0.69 | 1.05 | 0.64 | 0.59 | 0.54 | 1.12 | 2.04 | 3.72 | 1.84 |
| Firm Gas Customers | 0.41 | 0.41 | 0.35 | 0.27 | 0.23 | 0.21 | 0.17 | 0.15 | 0.16 | 0.17 | 0.25 | 0.35 | 0.26 |
| Chemical Plants | | | | | | | | | | | | | |
| Sulfur Recovery | 63.22 | 63.22 | 63.22 | 63.22 | 63.22 | 63.22 | 25.84 | 25.84 | 25.84 | 25.84 | 25.84 | 25.84 | 44.37 |
| Sulfuric Acid | 10.20 | 3.12 | 3.12 | 3.12 | 3.12 | 3.12 | 3.12 | 3.12 | 3.12 | 3.12 | 3.12 | 3.12 | 3.72 |
| Other Chemicals | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |
| Petroleum Refining and Production | | | | | | | | | | | | | |
| Fluid Catalytic Crackers | 45.48 | 45.48 | 45.48 | 45.48 | 45.48 | 45.48 | 45.48 | 45.48 | 45.48 | 45.48 | 45.48 | 45.48 | 45.48 |
| Sour Water Strippers | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| Delayed Cokers | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 |
| Misc. Refinery Processes | 0.86 | 0.86 | 0.86 | 0.86 | 0.86 | 0.86 | 0.86 | 0.86 | 0.86 | 0.86 | 0.86 | 0.86 | 0.86 |
| Oil Field Production | 5.17 | 5.17 | 5.17 | 5.17 | 5.17 | 5.17 | 5.17 | 5.17 | 5.17 | 5.17 | 5.17 | 5.17 | 5.17 |
| Misc. Stationary Sources | | | | | | | | | | | | | |
| Petroleum Coke Kilns | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 | 25.52 |
| Glass Furnaces | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Metals Industries | 8.76 | 8.76 | 8.76 | 8.76 | 8.76 | 8.76 | 8.76 | 8.76 | 7.40 | 7.40 | 7.40 | 7.40 | 8.31 |
| Mineral Products | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sewage Treatment Digesters | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 | 0.64 |
| Other Industrial Processes | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Permitted Incinerators | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| MOBILE SOURCES | | | | | | | | | | | | | |
| Autos and Lt. Trucks-Surface | 15.84 | 16.84 | 15.88 | 17.71 | 15.63 | 15.94 | 16.00 | 15.86 | 15.02 | 15.44 | 19.65 | 20.50 | 16.66 |
| Autos and Lt. Trucks-Freeway | 9.88 | 10.27 | 9.91 | 11.05 | 9.75 | 9.94 | 9.98 | 9.89 | 9.37 | 9.63 | 12.26 | 12.79 | 10.39 |
| Heavy Duty Vehicles-Surface | 11.20 | 11.65 | 11.25 | 12.49 | 12.65 | 12.95 | 13.03 | 12.95 | 12.27 | 12.66 | 12.53 | 13.11 | 12.40 |
| Heavy Duty Vehicles-Freeway | 6.99 | 7.27 | 7.02 | 7.79 | 7.89 | 8.08 | 8.13 | 8.08 | 7.65 | 7.90 | 7.81 | 8.18 | 7.74 |
| Airport Operations | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 |
| Shipping Operations | 9.38 | 9.38 | 9.38 | 9.38 | 9.38 | 9.38 | 9.38 | 9.38 | 9.38 | 9.38 | 9.38 | 9.38 | 9.38 |
| Railroad Operations | 2.87 | 2.87 | 2.87 | 2.87 | 2.87 | 2.87 | 2.87 | 2.87 | 2.87 | 2.87 | 2.87 | 2.87 | 2.87 |
| TOTAL | 421.31 | 359.83 | 325.69 | 307.02 | 320.86 | 342.31 | 297.63 | 269.27 | 309.71 | 339.13 | 400.61 | 427.02 | 343.24 |

# TABLE A2.16b

Major Off-Grid Emission Sources Included within the 1974 South Coast Air Basin Sulfur Oxides Modeling Inventory
(in short tons per day as $SO_2$)

| STATIONARY SOURCES | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel Combustion | | | | | | | | | | | | | |
| Electric Utilities | 67.54 | 65.53 | 39.48 | 26.51 | 34.32 | 47.56 | 49.39 | 51.69 | 51.22 | 46.91 | 56.15 | 68.58 | 50.34 |
| Refinery Fuel | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Other Interruptible Gas Customers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Firm Gas Customers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Chemical Plants | | | | | | | | | | | | | |
| Sulfur Recovery | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sulfuric Acid | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Other Chemicals | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Petroleum Refining and Production | | | | | | | | | | | | | |
| Fluid Catalytic Crackers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sour Water Strippers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Delayed Cokers | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Misc. Refinery Processes | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Oil Field Production | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Misc. Stationary Sources | | | | | | | | | | | | | |
| Petroleum Coke Kilns | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Glass Furnaces | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 |
| Metals Industries | 38.12 | 38.12 | 38.12 | 38.12 | 38.12 | 38.12 | 38.12 | 38.12 | 38.12 | 38.12 | 38.12 | 38.12 | 38.12 |
| Mineral Products | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 |
| Sewage Treatment Digesters | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Other Industrial Processes | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Permitted Incinerators | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TOTAL | 107.79 | 105.78 | 79.73 | 67.76 | 74.57 | 87.81 | 89.64 | 91.94 | 91.47 | 87.16 | 96.40 | 108.83 | 90.59 |

categories of Figure A2.43. The emissions inventory created for air quality model use contains spatially resolved source strength data defined on the 50 by 50 mile grid for each of the 26 source types shown in Tables A2.14 through A2.16 for each month of the years 1972 through 1974. An itemization of large off-grid sources is also included.

One principal reason for compiling emissions on a source by source basis is to be able to display the spatial distribution of $SO_x$ emission strength. Figures A2.45 through A2.47 summarize annual average $SO_x$ emissions density for the years 1972, 1973 and 1974 respectively. It is seen that the largest $SO_x$ emission source densities are located in a narrow strip along the coastline stretching from Los Angeles International Airport (near Lennox) on the north to Huntington Beach (opposite Santa Ana) on the south.

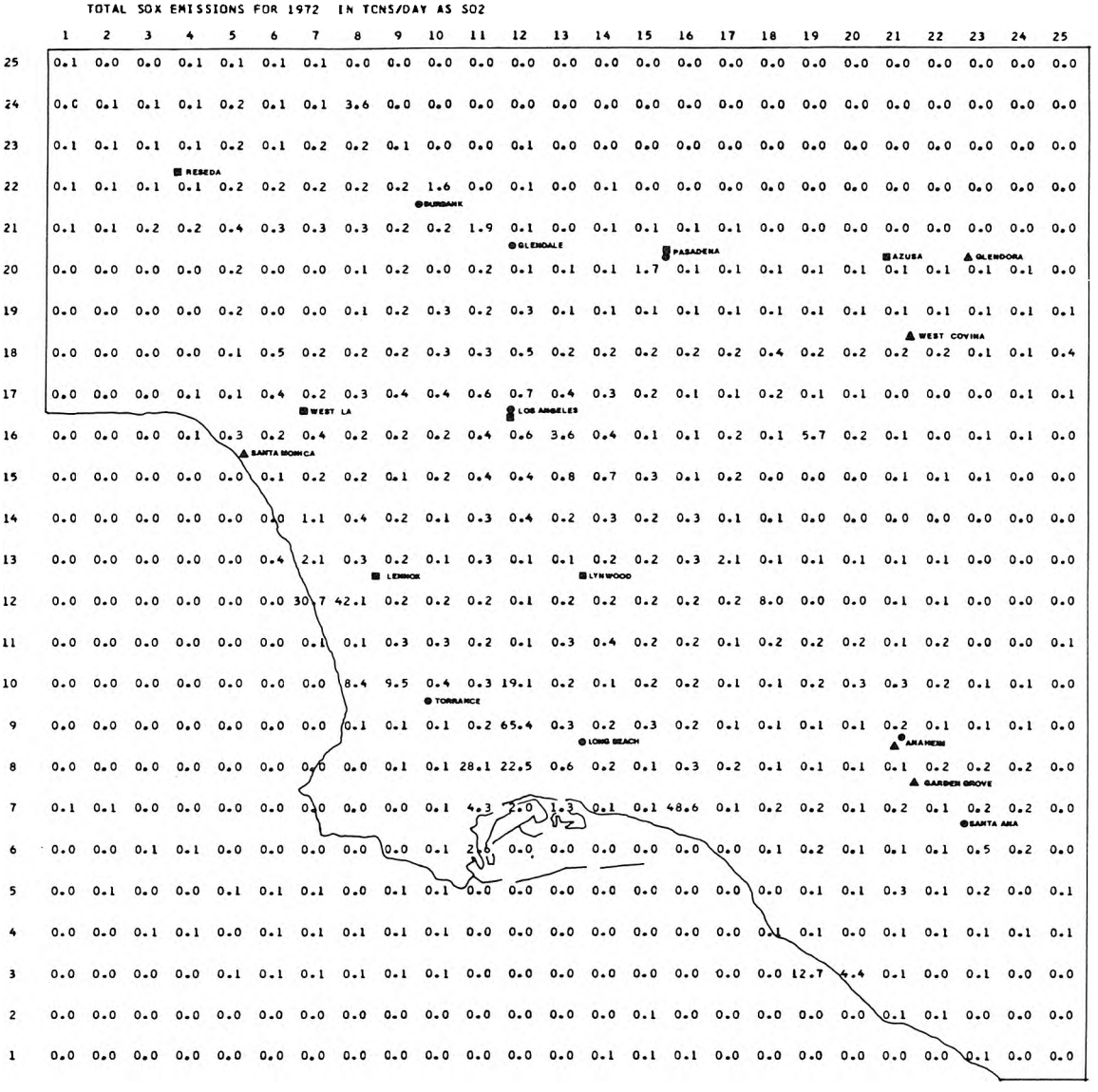

TOTAL SOX EMISSIONS FOR 1972 IN TONS/DAY AS SO2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
25 0.1 0.0 0.0 0.1 0.1 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
24 0.0 0.1 0.1 0.1 0.2 0.1 0.1 3.6 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
23 0.1 0.1 0.1 0.1 0.2 0.1 0.2 0.2 0.1 0.0 0.0 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
22 0.1 0.1 0.1 0.1 0.2 0.2 0.2 0.2 0.2 1.6 0.0 0.1 0.0 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
21 0.1 0.1 0.2 0.2 0.4 0.3 0.3 0.3 0.2 0.2 1.9 0.1 0.0 0.1 0.1 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
20 0.0 0.0 0.0 0.0 0.2 0.0 0.0 0.1 0.2 0.0 0.2 0.1 0.1 0.1 1.7 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.0
19 0.0 0.0 0.0 0.0 0.2 0.0 0.0 0.1 0.2 0.3 0.2 0.3 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
18 0.0 0.0 0.0 0.0 0.1 0.5 0.2 0.2 0.2 0.3 0.3 0.5 0.2 0.2 0.2 0.2 0.2 0.4 0.2 0.2 0.2 0.2 0.1 0.1 0.4
17 0.0 0.0 0.0 0.1 0.1 0.4 0.2 0.3 0.4 0.4 0.6 0.7 0.4 0.3 0.2 0.1 0.1 0.2 0.1 0.1 0.0 0.0 0.0 0.1 0.1
16 0.0 0.0 0.0 0.1 0.3 0.2 0.4 0.2 0.2 0.2 0.4 0.6 3.6 0.4 0.1 0.1 0.2 0.1 5.7 0.2 0.1 0.0 0.1 0.1 0.0
15 0.0 0.0 0.0 0.0 0.0 0.1 0.2 0.2 0.1 0.2 0.4 0.4 0.8 0.7 0.3 0.1 0.2 0.0 0.0 0.0 0.1 0.1 0.1 0.0 0.0
14 0.0 0.0 0.0 0.0 0.0 0.0 1.1 0.4 0.2 0.1 0.3 0.4 0.2 0.3 0.2 0.3 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0
13 0.0 0.0 0.0 0.0 0.0 0.4 2.1 0.3 0.2 0.1 0.3 0.1 0.1 0.2 0.2 0.3 2.1 0.1 0.1 0.1 0.1 0.1 0.0 0.0 0.0
12 0.0 0.0 0.0 0.0 0.0 0.0 30.7 42.1 0.2 0.2 0.2 0.1 0.2 0.2 0.2 0.2 0.2 8.0 0.0 0.0 0.1 0.1 0.0 0.0 0.0
11 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.3 0.3 0.2 0.1 0.3 0.4 0.2 0.2 0.1 0.2 0.2 0.2 0.1 0.2 0.0 0.0 0.1
10 0.0 0.0 0.0 0.0 0.0 0.0 0.0 8.4 9.5 0.4 0.3 19.1 0.2 0.1 0.2 0.2 0.1 0.1 0.2 0.3 0.3 0.2 0.1 0.1 0.0
9 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.1 0.2 65.4 0.3 0.2 0.3 0.2 0.1 0.1 0.1 0.1 0.2 0.1 0.1 0.1 0.0
8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 28.1 22.5 0.6 0.2 0.1 0.3 0.2 0.1 0.1 0.1 0.1 0.2 0.2 0.2 0.0
7 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 4.3 2.0 1.3 0.1 0.1 48.6 0.1 0.2 0.2 0.1 0.2 0.1 0.2 0.2 0.0
6 0.0 0.0 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.1 2.6 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.2 0.1 0.1 0.1 0.5 0.2 0.0
5 0.0 0.1 0.0 0.0 0.1 0.1 0.1 0.0 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.3 0.1 0.2 0.0 0.1
4 0.0 0.0 0.1 0.1 0.0 0.1 0.1 0.1 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.0 0.1 0.1 0.1 0.1 0.1
3 0.0 0.0 0.0 0.0 0.1 0.1 0.1 0.1 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 12.7 4.4 0.1 0.0 0.1 0.0 0.0
2 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.0 0.0 0.0
1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.0 0.0
RESEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
SOX
TONS/DAY
389.130

FIGURE A2.45

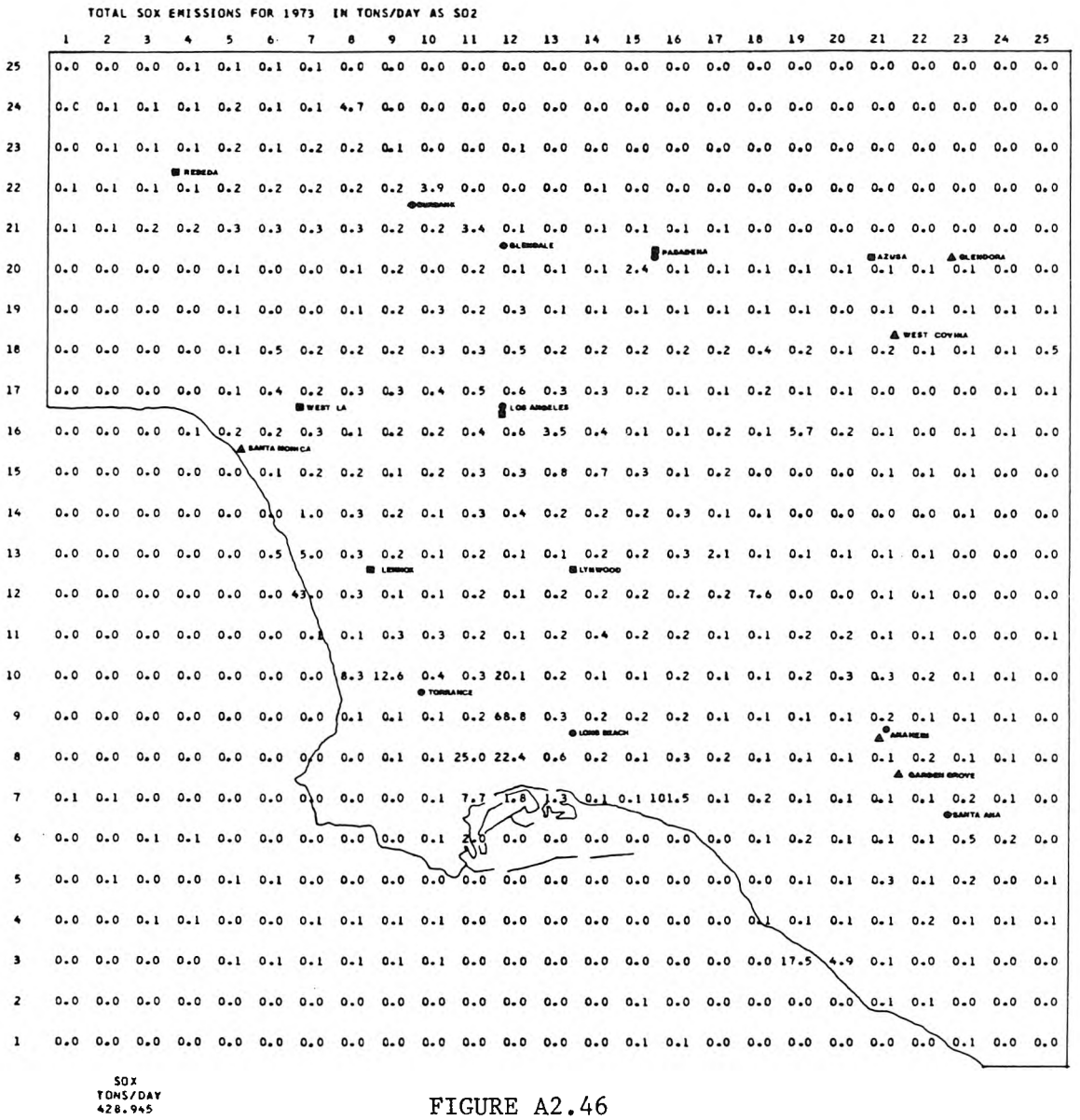

TOTAL SOX EMISSIONS FOR 1973 IN TONS/DAY AS SO2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
25 0.0 0.0 0.0 0.1 0.1 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
24 0.0 0.1 0.1 0.1 0.2 0.1 0.1 4.7 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
23 0.0 0.1 0.1 0.1 0.2 0.1 0.2 0.2 0.1 0.0 0.0 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
22 0.1 0.1 0.1 0.1 0.2 0.2 0.2 0.2 0.2 3.9 0.0 0.0 0.0 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
21 0.1 0.1 0.2 0.2 0.3 0.3 0.3 0.3 0.2 0.2 3.4 0.1 0.0 0.1 0.1 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
20 0.0 0.0 0.0 0.0 0.1 0.0 0.0 0.1 0.2 0.0 0.2 0.1 0.1 0.1 2.4 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.0 0.0
19 0.0 0.0 0.0 0.0 0.1 0.0 0.0 0.1 0.2 0.3 0.2 0.3 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.0 0.1 0.1 0.1 0.1 0.1
18 0.0 0.0 0.0 0.0 0.1 0.5 0.2 0.2 0.2 0.3 0.3 0.5 0.2 0.2 0.2 0.2 0.2 0.4 0.2 0.1 0.2 0.1 0.1 0.1 0.5
17 0.0 0.0 0.0 0.0 0.1 0.4 0.2 0.3 0.3 0.4 0.5 0.6 0.3 0.3 0.2 0.1 0.1 0.2 0.1 0.1 0.0 0.0 0.0 0.1 0.1
16 0.0 0.0 0.0 0.1 0.2 0.2 0.3 0.1 0.2 0.2 0.4 0.6 3.5 0.4 0.1 0.1 0.2 0.1 5.7 0.2 0.1 0.0 0.1 0.1 0.0
15 0.0 0.0 0.0 0.0 0.0 0.1 0.2 0.2 0.1 0.2 0.3 0.3 0.8 0.7 0.3 0.1 0.2 0.0 0.0 0.0 0.1 0.1 0.1 0.0 0.0
14 0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.3 0.2 0.1 0.3 0.4 0.2 0.2 0.2 0.3 0.1 0.1 0.0 0.0 0.0 0.0 0.1 0.0 0.0
13 0.0 0.0 0.0 0.0 0.0 0.5 5.0 0.3 0.2 0.1 0.2 0.1 0.1 0.2 0.2 0.3 2.1 0.1 0.1 0.1 0.1 0.1 0.0 0.0 0.0
12 0.0 0.0 0.0 0.0 0.0 0.0 43.0 0.3 0.1 0.1 0.2 0.1 0.2 0.2 0.2 0.2 0.2 7.6 0.0 0.0 0.1 0.1 0.0 0.0 0.0
11 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.3 0.3 0.2 0.1 0.2 0.4 0.2 0.2 0.1 0.1 0.2 0.2 0.1 0.1 0.0 0.0 0.1
10 0.0 0.0 0.0 0.0 0.0 0.0 0.0 8.3 12.6 0.4 0.3 20.1 0.2 0.1 0.1 0.2 0.1 0.1 0.2 0.3 0.3 0.2 0.1 0.1 0.0
9 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.1 0.2 68.8 0.3 0.2 0.2 0.2 0.1 0.1 0.1 0.1 0.2 0.1 0.1 0.1 0.0
8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 25.0 22.4 0.6 0.2 0.1 0.3 0.2 0.1 0.1 0.1 0.1 0.2 0.1 0.1 0.0
7 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 7.7 1.8 1.3 0.1 0.1 101.5 0.1 0.2 0.1 0.1 0.1 0.1 0.2 0.1 0.0
6 0.0 0.0 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.1 2.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.2 0.1 0.1 0.1 0.5 0.2 0.0
5 0.0 0.1 0.0 0.0 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.3 0.1 0.2 0.0 0.1
4 0.0 0.0 0.1 0.1 0.0 0.0 0.1 0.1 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.1 0.1 0.2 0.1 0.1 0.1
3 0.0 0.0 0.0 0.0 0.1 0.1 0.1 0.1 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 17.5 4.9 0.1 0.0 0.1 0.0 0.0
2 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.0 0.0 0.0
1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.0 0.0
REDEDA
GUNDARK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
SOX
TONS/DAY
428.945

FIGURE A2.46


TOTAL SOX EMISSIONS FOR 1974 IN TONS/DAY AS SO2
RESEDA
BURBANK
GLENDALE
PASADENA
AZUSA
GLENDORA
WEST COVINA
WEST LA
LOS ANGELES
SANTA MONICA
LENNOX
LYNWOOD
TORRANCE
LONG BEACH
ANAHEIM
GARDEN GROVE
SANTA ANA
SOX
TONS/DAY
343.244

FIGURE A2.47

## References for Appendix A2

Birakos, J. N. (1974), 1974 Profile of Air Pollution Control, County of Los Angeles, Los Angeles Air Pollution Control District.

Bureau of Mines (1972d through 1974d), Diesel Fuel Oils, 1972, (73, 74), U. S. Department of the Interior, Mineral Industry Surveys, Petroleum Product Survey No. 77, 82, 87.

Bureau of Mines (1972f through 1975f), Motor Gasolines, Winter 1971-1972 (also Summer 1972, Winter 1972-1973, Summer 1973, Winter 1973-1974, and Summer 1974), U. S. Department of the Interior, Mineral Industry Surveys, Petroleum Products Surveys No. 75, 78, 80, 83, 85, 88. For continuation of series, see Shelton (1975).

California Department of Public Works (1969 and 1972), 1969 Traffic Volumes on the California State Highway System (also 1972 edition), Sacramento, California, Business and Transportation Agency, State of California.

California Department of Transportation (1973 and 1974), 1973 Traffic Volumes on the California State Highway System (also 1974 edition), Sacramento, California, Business and Transportation Agency, State of California.

California Department of Transportation (1975), 1974 Socioeconomic Characteristics, Los Angeles Regional Transportation Study, LARTS Regional Profile (display maps). Maps drawn at a larger scale were also made available by Cal Trans.

California Public Utilities Commission (1976), 10-Year Forecast of Gas Utilities' Requirements and Supplies, 1976-1985, San Francisco, California, staff report S-2249.

Cantrell, A. (1973), "Annual Refining Survey", The Oil and Gas Journal, Vol. 71, No. 14, April 2, 1973.

Environmental Protection Agency (1973), Compilation of Air Pollutant Emission Factors, Second Edition, Research Triangle Park, North Carolina, U. S. Environmental Protection Agency document No. AP-42.

Environmental Protection Agency (1975), Supplement No. 5 For Compilation of Air Pollutant Emission Factors, Second Edition, Research Triangle Park, North Carolina, Supplement to U. S. Environmental Protection Agency document No. AP-42.

Ethyl Corporation (1974), Yearly Report of Gasoline Sales by State.

Hunter, S. C. and N. L. Helgeson (1976), Control of Oxides of Sulfur from Stationary Sources in the South Coast Air Basin of California, Tustin, California, KVB Incorporated, Document No. KVB-5802-432, prepared under California Air Resources Board Contract No. ARB 4-421.

Kaye, M. (1976), Southern California Air Pollution Control District - Southern Zone, personal communication.

Krumwiede, K. A. (1976), Southern California Edison Company, personal communication, June 9, 1976.

Lemke, E. et al. (1971), Profile of Air Pollution Control in Los Angeles County, 1971 edition, County of Los Angeles, Los Angeles Air Pollution Control District.

Los Angeles Air Pollution Control District (1975), "History and Outlook of Emissions of Sulfur Dioxide in Los Angeles County", table dated November 21, 1975.

Menkus, S. (1976), Southern California Air Pollution Control District, personal communication.

1975 California Gas Report, prepared pursuant to California Public Utilities Commission Decision No. 62260.

Nordsieck, R. A. (1974), Air Quality Impacts of Electric Cars in Los Angeles, Appendix A, Pollutant Emissions Estimates and Projections for the South Coast Air Basin, Santa Barbara, California, General Research Corporation document RM-1905-A.

Orange County Road Department (1963-1969, 1970-1973, 1974), Annual Traffic Census, 1963-1969 edition, 1970-1973 edition, 1974 edition.

Rojas, R. (1976), City of Los Angeles, Hyperion Treatment Plant, personal communication, June 17, 1976.

Roth, P. M., P. J. W. Roberts, M-L Liu, S. D. Reynolds, and J. H. Seinfeld (1974), Atmospheric Environment, 8, 97.

Shelton, E. M. (1975), Motor Gasolines, Winter 1974-75 , U. S. Energy Research and Development Administration Publication BERC/PPS-75/1.

Simon, H. (1976), Southern California Air Pollution Control District, personal communication.

Sjovold, A. R. (1973), Electrical Energy Projections for the Los Angeles Region, 1980-2000, General Research Corporation document RM-1859 (as cited by Nordsieck, 1974).

Smith, J. (1976), Kaiser Steel Corporation, Fontana, California, personal communication.

Southern California Air Pollution Control District, Personal Communication (1976a). The District furnished censored versions of the following internal documents:

(1) "Sulfur Balance - Los Angeles County Refineries - 1973".
(2) "Sulfur Balance - Los Angeles County Refineries - 1974".
(3) "Sulfur Recovery and Sulfuric Acid Plant Operations - Los Angeles County - 1973".
(4) "Sulfur Recovery and Sulfuric Acid Plant Operations - Los Angeles County - 1974".

All documents were censored to conceal sulfur and acid production data for individual refineries and chemical plants while summarizing activities for the county as a whole. Atmospheric emissions were, however, apparent on a plant by plant basis.

Southern California Air Pollution Control District (1976b), "Major Point Sources of Air Pollution in the Four Counties Served by the Southern California APCD", El Monte, California, Southern California Air Pollution Control District list dated April, 1976.

Southern California Edison (1973), Financial and Statistical Report, 1973, Rosemead, California.

Taylor, J. (1976), Southern California Air Pollution Control District, personal communication. Provided a copy of a large Los Angeles APCD map showing the APCD's grid system laid over Los Angeles and Orange Counties.

Thomas Brothers Maps (1975), Los Angeles - Orange Counties Popular Street Atlas, 1975 edition, Los Angeles, California, Thomas Brothers Maps.

Wood, W. (1977), California Air Resources Board, personal communication, February 2, 1977. Provided sales by county to firm, interruptible, and steam electric customers of the Southern California Gas Co. and the Long Beach Gas Department for the years 1972, 1973 and 1974.

Zwiacher, W. (1976), Southern California Air Pollution Control District, personal communications, numerous dates, 1976.

# APPENDIX A3

## ENERGY AND SULFUR BALANCE CALCULATIONS FOR THE SOUTH COAST AIR BASIN - 1973

### A3.1 Introduction

This appendix describes the data sources and methods that were employed to compile an energy balance on the economy of the South Coast Air Basin for the year 1973. The purpose of this study was to determine the sources and sinks for sulfur-bearing fossil fuels within this air basin in a way that would assist estimation of sulfur oxides air pollutant emissions. Therefore, the energy balance is followed by sulfur balance calculations.

During the course of this discussion, it will become necessary to convert physical quantities of fuels (e.g. barrels, gallons, mcf) into energy units. A list of the conversion factors which were used in the development of this energy balance is given in Table A3.1. English engineering units are employed throughout this appendix since that is the currently accepted practice in the governmental and industrial community from whom the data used in this report were obtained.

The nature of energy resources as they enter the South Coast Air Basin will first be described. Then energy resources supplied to local petroleum refineries and electric utility generating stations will be transformed into a variety of finished petroleum products and electricity. Finished products reaching the end use consumption

TABLE A3.1

Heating Values and Conversion Factors

| Fuel | Heating Value | Reference |
|---|---|---|
| Natural Gas | 1060 BTU/$ft^3$ | 1975 California Gas Report |
| Crude Oil | 5800 x $10^3$ BTU/bbl | American Petroleum Institute (1972) |
| LPG | | |
| Propane | 3800 x $10^3$ BTU/bbl | Environmental Protection Agency (1973) |
| Butane | 4090 x $10^3$ BTU/bbl | Environmental Protection Agency (1973) |
| Average | 3950 x $10^3$ BTU/bbl | (Used when no composition data available) |
| Natural Gasoline | 4620 x $10^3$ BTU/bbl | Bureau of Mines (1975c) |
| Digester Gas | 600 BTU/$ft^3$ | Frieling (1976) |
| Still Gas | 990 BTU/$ft^3$ | Bureau of Mines (1975c) |
| | 6000 x $10^3$ BTU/bbl | Bureau of Mines (1975c) |
| Refinery Gas (LPG & still gas mixture) | 1300 BTU/$ft^3$ | Zwiacher (1976) |
| Gasoline | 5248 x $10^3$ BTU/bbl | Bureau of Mines (1975c) |
| Diesel Fuel | 5812 x $10^3$ BTU/bbl | List (1971) |
| Jet Fuel | 5683 x $10^3$ BTU/bbl | List (1971) |
| Fuel Oils | | |
| Distillate | 5825 x $10^3$ BTU/bbl | Bureau of Mines (1975c) |
| Residual | 6287 x $10^3$ BTU/bbl | Bureau of Mines (1975c) |
| Lubricants | 6065 x $10^3$ BTU/bbl | Bureau of Mines (1975c) |
| Asphalt | 6636 x $10^3$ BTU/bbl | Bureau of Mines (1975c) |
| Petroleum Coke | 6024 x $10^3$ BTU/bbl | Bureau of Mines (1975c) |
| Miscellaneous Petroleum Products | 5800 x $10^3$ BTU/bbl | (Based on energy content of crude oil) |
| Coal | 12,000 BTU/lb | Bureau of Mines (1975c) |
| Electricity | 3412 BTU/kwh | American Petroleum Institute (1972) |
| Steam | 1200 BTU/lb | Bureau of Mines (1975c) |

sector of the air basin's economy will be outlined, followed by an estimate of energy exports from the basin. The sulfur balance will follow from the energy balance in the same order. Throughout the discussion, the word "imports" will be used to indicate flows of energy (or sulfur) across the boundaries of the air basin and will be applied to both foreign and out-of-basin domestic sources. Similarly the term "exports" will be applied to flows out of the basin whether to foreign or domestic customers.

## A3.2 Energy Sources

An estimate of the South Coast Air Basin's original energy supply is given in Table A3.2 for the year 1973. These data represent inflows of energy resources across the boundaries of the air basin, including locally produced oil and gas. All values given are in $10^{12}$ BTU's per year. Crude oil is seen to be the largest single energy source for the basin, followed by natural gas and imported fuel oils. A description of the methods used to estimate the quantities shown in Table A3.2 follows.

### A3.2.1 Natural Gas Sources

All data on natural gas supplies were taken from the 1975 California Gas Report. Gas is received from both California and interstate suppliers. Natural gas from California sources is broken down into two components: direct purchases by the gas and electric utilities serving the basin, plus gas received for exchange. A gas exchange transaction represents gas submitted by its owner to a pipeline at one location followed by a counterbalancing withdrawal of gas from

TABLE A3.2

South Coast Air Basin Energy Sources-1973

| | $10^{12}$ BTU/year |
|---|---|
| Natural Gas | |
| California sources-utility purchase | 67.7 |
| -gas exchange | 30.1 |
| Interstate receipts | 945.0 |
| Purchases from other utilities | 7.5 |
| Less net injection to storage | -25.2 |
| Subtotal | 1,025.1 |
| Crude Oil Plus Net Unfinished Oils | |
| Los Angeles & Ventura area oil fields | 1,039.8 |
| Other California crude oils | 276.7 |
| Interstate receipts of domestic oils | 225.9 |
| Foreign imports | 639.9 |
| Subtotal | 2,182.3 |
| Petroleum Product Imports | |
| Harbor receipts | |
| Gasoline (including natural gasoline) | 69.6 |
| Jet fuel | 4.4 |
| Distillate oil and kerosene | 83.6 |
| Residual oil | 127.6 |
| Petroleum coke | 5.5 |
| Lubricants and greases | 12.3 |
| Asphalt and asphalt materials | 0.1 |
| Other | 4.6 |
| Subtotal | 307.7 |
| Natural Gasoline & Natural Gas Liquids | 20.9 |
| Liquid Petroleum Gas | 14.4 |
| Digester Gas | 2.6 |
| Electricity Imports | |
| Generated out-of-basin by local utilities | |
| Nuclear | 6.2 |
| Hydro | 27.2 |
| Fossil fuel | |
| Oil | 0.03 |
| Natural gas | 3.8 |
| Coal | 34.8 |
| Purchases out-of-basin | 25.3 |
| Less out-of-basin sales | -13.1 |
| Subtotal | 84.2 |
| Coal | |
| Coking coal | 57.2 |
| Miscellaneous | 0.2 |
| Receipts for export | 0.0 |
| Subtotal | 57.4 |
| TOTAL ENERGY SOURCES | 3,694.6 |

the pipeline system at another location. Gas transferred through the utility systems serving the basin to San Diego and other areas of the state are included in the gas-supply totals of Table A3.2, and will be subtracted from the South Coast Air Basin's supply later as an "export".

Gas purchases by one utility company from another are not identifiable by interstate or intrastate origin. Purchases from other utilities shown in the energy supply tabulation include only those made by Pacific Lighting Companies. Purchases by Southern California Edison (SCE) from Pacific Gas and Electric (PG&E) for SCE's Coolwater power plant (located in the Mojave Desert) have not been included since that power plant site lies outside of the South Coast Air Basin. Those purchases were discussed in the PG&E section of the 1975 California Gas Report as "sendout to other steam electric plants, retail". All other utility to utility transactions reported by Los Angeles area utility companies represent purchases from Pacific Lighting and thus do not constitute a net flow of gas into the air basin's economy.

Changes in gas storage from one year to the next also take place. Storage change data were taken from the 1975 California Gas Report under the headings "underground and LNG storage injection" and "underground and LNG storage withdrawal". Depending on whether withdrawal exceeds injection or not, this activity could constitute a net gas source or sink in any given year. In 1973, injection exceeded

withdrawal and the effect of the storage program was to reduce available gas supplies.

### A3.2.2 Crude Oil Sources

A detailed survey of the South Coast Air Basin's crude oil supply was conducted for the year 1973, and is reported in Appendix A1 to this study. Data from that survey are the basis for the crude oil sources reported in Table A3.2. Crude oil sources have been grouped into local oil fields (i.e. oil produced at fields within the South Coast Air Basin and Federal leases off the coast of the air basin), other California oil fields (e.g. from the San Joaquin Valley and the central California coastal area), other domestic oils (from Alaska and the Four Corners area), and foreign crude oil. Sources of Los Angeles and Ventura area crude oil given in Table A3.2 include all production from those fields in 1973 (see Table A1.6). Net out-of-basin shipments of some of this locally produced crude oil will be subtracted from the energy balance later an an "export". All other crude oil volumes represent imports from out-of-basin sources as given in Table A1.10.

### A3.2.3 Imported Petroleum Product Sources

Data on port receipts of refined petroleum products were obtained from Waterborne Commerce of the United States (Corps of Engineers, 1973). In those cases where harbor records do not distinguish between imports and exports,refined products were assumed to be shipped to sea from El Segundo and received at Huntington Beach, Ventura, Port Hueneme, and Carpenteria. Whenever a product

classification used by the Corps of Engineers encompasses more than one product type, the entire energy content of imports in that classification was assigned to the most prominant product in the group.

No indication was found that significant quantities of refined petroleum products intended for civilian use were received in the South Coast Air Basin by means other than waterborne transit.

### A3.2.4 Natural Gas Liquids* (NGL) and Liquified Petroleum Gas (LPG) Sources

Total production of these liquids at West Coast natural gas processing plants in 1973 is given by the Bureau of Mines (1974g, 1975e). West Coast import data likewise are available in the same publications. But scale factors needed to estimate transfers of LPG and NGL from West Coast suppliers to the South Coast Air Basin seem largely unavailable.

The California Energy Planning Council (1974) is able to supply an estimate of 1973 LPG and natural gasoline supplies for the entire state of California. They place total availability of natural gasoline at 20,000 bbl/day and LPG at 20,000 bbl/day. Natural gasoline appears to be used principally as a refinery feedstock. The refinery discussion to be presented later in this appendix indicates that 62% of the state's crude oil runs to refineries in 1973 occured in the South Coast Air Basin. Therefore, 62% of the available supply of natural

*Including natural gasoline.

gasoline in California in that year was assigned to the South Coast Air Basin.

LPG is used as a refinery fuel, for chemical plant feedstock, and for a variety of domestic and light industrial applications. Fifty percent of California's available LPG input was assigned to the South Coast Air Basin in 1973 on the basis of the ratio between basin population and the population of the state.

### A3.2.5 Sources of Digester Gas

As part of the sewage sludge digestion process, methane-rich gases are produced. This digester gas is burned to power the sewage treatment plants, and is also sold for fuel to nearby industries and power plants. The volumes of digester gas produced by the Orange County Sanitation District, the City of Los Angeles' Hyperion Treatment Plant and the Los Angeles County Sanitation District's Harbor City plant were determined by conversations with treatment plant personnel (personal communications: Clark, 1976; Rojas, 1976; Frieling, 1976). The energy content of digester gas was given as 600 BTU/$ft^3$ (personal communication, Frieling, 1976).

### A3.2.6 Sources of Imported Electricity

Southern California Edison Company (SCE), the Los Angeles Department of Water and Power (DWP), and the municipal power departments of Pasadena, Burbank, and Glendale are the utilities involved in importing electricity into the South Coast Air Basin. Data on quantities of electricity imported and generated by various methods were obtained from the annual reports of these utilities (Pasadena, 1974, 1975; Department of Water and Power, 1972a through 1975a, 1975b;

Southern California Edison, 1972a; 1973a; Southern California Edison, 1974). Additional data sources employed include the Federal Power Commission's (FPC) yearly reports on Statistics of Privately Owned Electric Utilities in the United States (Federal Power Commission, 1972a, 1973a, 1974a) and Statistics of Publicly Owned Electric Utilities in the United States (Federal Power Commission 1972b, 1973b, 1974b), plus the FPC's monthly reports on Electric Power Statistics (Federal Power Commission 1972c through 1975c).

Data available for the various utility companies were provided in different formats and required further processing before they could be combined to summarize electricity imports for the whole basin. Data for SCE were available on a calendar year basis in both the company's annual reports and the FPC yearly reports. For the other publicly owned utilities, data were provided only on a fiscal year basis. To adjust fiscal year data to a calendar year basis, the FPC monthly systems load data for each utility were examined to determine the load distribution between the two calendar years spanned by a given fiscal year. The factors shown in Table A3.3 were used to assign fiscal year data (for both electric generation and end use consumption) to given calendar years.

Nuclear power is imported to the air basin's economy from SCE operations at San Onofre. Data on nuclear power generation were taken from the SCE annual reports.

Hydroelectric power is produced by the DWP and SCE at installations at Hoover Dam and other sites. Data on total production of

TABLE A3.3

Factors Used to Adjust Electric Utility Fiscal Year
Data to a Calendar Year Basis

| | Percentage of Fiscal Year Electric System Load Assigned to First and Second Half of Each Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | DWP | | Pasadena | | Glendale | | Burbank | |
| Fiscal Year | 1st Half | 2nd Half | 1st Half | 2nd Half | 1st Half | 2nd Half | 1st Half | 2nd Half |
| 72-73 | 55.6 | 44.4 | 51.2 | 48.8 | 51.2 | 48.8 | 51.1 | 48.9 |
| 73-74 | 54.5 | 45.4 | 54.5 | 45.5 | 54.7 | 45.3 | 55.6 | 44.4 |

hydroelectric power were taken from the annual reports of these two utilities. The DWP pumped storage facility at Castaic was not included in the imported hydropower numbers on the energy balance. Electric power output from that reservoir will be considered as the result of in-basin hydroelectric generation to be described later in this appendix.

The DWP and SCE also have fossil fuel fired generating facilities located outside of the South Coast Air Basin. The DWP's out-of-basin plants are all coal fired; their electric production in fiscal years 1973-74 and 1974-75 is reported in the DWP's 1974-75 annual report. Coal fired electricity production for previous years was not reported separately in the DWP annual reports, but that information was obtained by personal communication with DWP staff (Nelson, 1976).

SCE's out-of-basin thermal generation includes coal fired plants plus the oil and gas fired plant at Coolwater in the Mojave Desert. Coal fired electricity production was reported separately in their 1973 annual statistical report. Gas and oil fired generation of electricity at Coolwater was estimated from PG&E's deliveries and curtailment of natural gas to the Coolwater plant (1975 California Gas Report) using the average heat rate from SCE's annual statistical report. Generation from natural gas at Coolwater was based on gas delivered, while gas deliveries curtailed were assumed to represent (on an equivalent BTU basis) the amount of oil that had to be burned instead.

Purchased power shown in Table A3.2 represents the sum of all purchases by electric systems from sources other than their own

generating facilities. These purchases are assumed to come from out-of-basin generating plants. The quantity of sales between utilities of electricity generated within the basin could not be determined, but is estimated to be small in 1973. Data on purchases were taken from the FPC annual reports, with the following exception. Los Angeles DWP purchases were taken from their 10-year summary of operations published in 1975 (Department of Water and Power, 1975b).

Both the DWP and SCE provide electrical service to areas located outside of the South Coast Air Basin. The exact source of the electricity used to supply these customers is not known. In this energy balance, out-of-basin electricity consumption on these two utility systems has been subtracted from total out-of-basin electricity supply. The DWP services to Inyo and Mono Counties are reported for each year in the DWP 10-year summary (Department of Water and Power, 1975b). The SCE reports give no data on electricity use by geographic area. However, by comparing statistics on population, industrial employees, and number of manufacturing firms in the counties served by SCE, it was estimated that 92% of their residential and commercial sales, 98% of industrial sales, 10% of agricultural sales and 92% of "other" sales were for use within the South Coast Air Basin. Derivation of these scale factors will be explained when discussing electricity end use consumption. The remaining SCE electric use in each category was assigned to out-of-basin sales. Total SCE and DWP out-of-basin sales were then subtracted from out-of-basin sources to determine the net out-of-basin electricity supply shown on the energy input tabulation of Table A3.2.

### A3.2.7 Sources of Coal

The 1973 Minerals Yearbook (Bureau of Mines, 1975e) indicates that coal use in California was confined almost entirely to coke and gas production during 1973. The Stanford Research Institute (1973) report Meeting California's Energy Requirements,1975-2000 assigns all coal use in the state to Southern California. The principal recipient of coking coal in Southern California is a steel mill located within the bounds of the South Coast Air Basin. On that basis, all coal shipped to California for coke and gas production was assigned to the South Coast Air Basin.

The Bureau of Mines' Minerals Yearbook (1975e) also lists a very small amount of coal shipped to California for miscellaneous retail sales. Half of this retail coal sale has been assigned to the South Coast Air Basin (on the basis of basin population as a fraction of total state population).

## A3.3 Energy Transformations Occurring Within the South Coast Air Basin

### A3.3.1 Petroleum Refining

#### A3.3.1.1 Crude Oil and Other Raw Material Inputs to the Refining Process

Data on 1973 West Coast (PAD District V) refinery input feedstocks are available from the Bureau of Mines (1975c). Similar information on total 1973 California refinery feedstocks is given by the California Energy Planning Council (1974). These data are summarized in Table A3.4.

TABLE A3.4

1973 Refinery Input and Output
(in $10^{12}$ BTU's/year)

| | PAD District V* (West Coast) | California | South Coast Air Basin | South Coast Air Basin Adjusted |
|---|---|---|---|---|
| Refinery Input Feedstocks (total) | 4,372.2 | 3,510.6 | 2,174.3 | |
| Crude & net unfinished oils | 4,260.2 | 3,430.6 | 2,124.8 | |
| LPG | 28.2 | 14.1 | 8.7 | |
| NGL (natural gasoline) | 39.5 | 38.6 | 23.9 | |
| (condensate) | 16.5 | | | |
| Other hydrocarbons | 27.5 | 27.3 | 16.9 | |
| Fuels Consumed (total) | 470.6 | | 219.9 | |
| Natural gas | 150.2 | | 48.5 | |
| Refinery gas | 184.6 | | 149.8 | |
| LPG | 13.4 | | | |
| Residual & heavy distillate oil | 31.1 | | 11.8 | |
| Middle distillate oil | 6.9 | | | |
| Petroleum coke | 58.8 | | | |
| Electricity | 19.7 | | 9.8 | |
| Steam | 5.9 | | unknown | |
| Refinery Output (total) | 4,446.9 | 3,582.1 | 2,218.6 | |
| Gasolines | 1,759.6 | 1,393.3 | 863.0 | |
| Jet fuels | 490.1 | 362.2 | 224.3 | |
| Distillate oils and kerosene | 605.3 | 435.2 | 269.5 | |
| light and mid distillates | | | | 126.9 |
| heavy distillate & residual oils | | | | 581.2 |
| Residual oils | 835.5 | 708.2 | 438.6 | |
| Petroleum coke | 200.2 | | | 112.0 |
| LPG-LRG | 64.5 | | | 36.1 |
| Lubricants | 33.0 | | | 18.5 |
| Asphalt & road oil | 157.2 | | | 88.0 |
| Still gas for fuel | 193.7 | | | 108.4 |
| Other hydrocarbons | 107.8 | 683.2 | 432.2 | 60.3 |

*PAD District V includes the states of Alaska, Arizona, California, Hawaii, Nevada, Oregon and Washington.

The net supply of crude and unfinished oils available to South Coast Air Basin refineries in 1973 was established in Appendix A1 to this study (see Table A1.10). Crude and net unfinished oils processed by South Coast Air Basin refineries appear to account for about 62% of the crude oil and net unfinished oil supplied to all refineries in California in that year. That proportion of total South Coast Air Basin to total State crude oil input was used to scale the other non-crude oil refinery feedstocks given for all of California in Table A3.4 down to an estimate for the South Coast Air Basin.

A3.3.1.2 Refinery Fuel Use

Fuel use at refineries in PAD District V is reported by the Bureau of Mines (1975c). Fuel combustion by South Coast Air Basin refineries was calculated from a refinery fuel survey conducted by the Southern California Air Pollution Control District (SCAPCD) as described in Appendix A2 of this study. That local refinery survey covers all large refineries in the South Coast Air Basin, but at least two very small independent refiners are neglected. Therefore, total fuel use estimates for local refineries given in Table A3.4 will be a few percent too low.

Total refinery gas consumption reported to the SCAPCD by local refineries includes a mix of still gas and LPG. Oil use reported is for both residual and distillate fuels. In Table A3.4, these locally reported fuel combinations which overlap more than one Bureau of Mines fuel use category are shown by a single heating value estimate contained within a box which spans the equivalent combination of fuels

reported by the Bureau of Mines. Electricity consumption by South Coast Air Basin refineries was scaled from PAD District V refinery electricity use in proportion to the ratio between South Coast Air Basin and PAD District V crude plus net unfinished oils feedstock inputs.

A3.3.1.3 Refinery Products

The product output of West Coast refineries in 1973 is available in considerable detail from the Bureau of Mines (1975c). The California Energy Planning Council (1974) reports 1973 California refinery production data for most liquid fuels plus a single miscellaneous refinery products category. A summary of these product data are given in Table A3.4.

Using crude oil input to refineries as our scaling factor, 62% of the total California refinery output of each product listed by the California Energy Planning Council (1974) was assigned to the South Coast Air Basin. Then the California Energy Planning Council's miscellaneous product category was subdivided further. Estimates of local refinery production of petroleum coke, LPG-LRG, lubricants, asphalt, still gas and other hydrocarbons were derived from the South Coast Air Basin's share of the state's miscellaneous products total in proportion to PAD District V refinery production of these items.

From a review of the quantity of heavy oils burned in the South Coast Air Basin, it became apparent that some of the product output listed as "distillate" by the Bureau of Mines was actually being

blended into the heavy fuel oil pool. Therefore, an attempt was made to estimate the magnitude of this blending operation.

Distillate oils were subdivided into a light and middle distillates group, plus a heavy distillate group. The heavy distillate oils were then lumped with residual oil to form a single heavy fuel oil category. The quantity of heavy distillate oil produced in the South Coast Air Basin was estimated from a knowledge of the tonnage of sulfur contained in such oils leaving local refineries in 1973 as reported by the Southern California Air Pollution Control District (1976a), combined with an estimate of the weight percent sulfur in a Western Region Grade 4 fuel oil given by the Bureau of Mines (1972b). These revisions to the quantities of light and heavy fuel oils produced in South Coast Air Basin refineries are shown as an adjustment in Table A3.4.

### A3.3.2 Generation of Electricity Within the South Coast Air Basin

Energy resources used to generate electricity within the South Coast Air Basin in 1973 are detailed in Table A3.5. These estimates are based on data from the sources cited during our previous discussion of electric power imports from outside of the basin. The quantity of electricity produced by combustion of various fuels was first determined from utility statistical reports. Then that electricity production by fuel type was combined with a knowledge of typical generating station heat rates to estimate total fuel input to the generating plant .

Thermal electric generation capacity is of two types: conventional steam boilers and internal combustion engines. With the

TABLE A3.5

Electricity Generation Within
the South Coast Air Basin - 1973

| Fuel Burned | $10^{12}$ BTU/year |
|---|---|
| Natural Gas | 160.8 |
| Heavy Fuel Oil | 386.3 |
| Light Distillate Oils | 2.7 |
| Digester Gas | 0.3 |
| SUBTOTAL | 550.1 |
| **Electricity Generated** | |
| Thermal Generating Plants | 175.5 |
| Hydroelectric | 0.4 |
| SUBTOTAL | 175.9 |

exception of the City of Pasadena, all basin electric utilities employed internal combustion turbines to generate peaking power during 1973. Peaking unit utilization is reported in the FPC annual statistical reports, sometimes as "internal combustion engine" generation and sometimes as "other" generation. A light distillate fuel is assumed to be burned in these turbines.

Data on conventional steam electricity generation occurring within the South Coast Air Basin must be separated from statistics representing total conventional steam electric generation on each utility's entire system. In the case of DWP, this separation is readily identifiable in their annual reports. DWP's out-of-basin steam electric production is all coal-fired, while in-basin plants run on oil and gas. All 1973 conventional steam electric generation by the cities of Glendale, Burbank and Pasadena occurred within the air basin. SCE's in-basin steam electric generation for 1973 was determined by subtracting all coal-fired generation plus SCE's out-of-basin oil and gas fired generation from their total system steam electrical generation as given in their annual statistical reports. Estimation of SCE's out-of-basin oil and gas fired electricity generation was discussed previously in Section A3.2.6 of this survey. In-basin electricity generation at conventional steam plants by all utilities was then totaled for the year 1973.

Next, this in-basin electricity output from conventional generating stations was used to estimate related utility oil and gas requirements. The energy input required to generate the total

steam electric output determined above was calculated using SCE's average heat rate, which was 9947 BTU's/KWH in 1973. The energy content of natural gas supplied to electric utilities in 1973 was calculated from gas deliveries to generating stations as reported in the 1975 California Gas Report. The remaining heat required to complete the total input to the steam electric generation process was assumed to be supplied by burning heavy fuel oil. These fuel use estimates derived from utility annual reports are very close to those obtained by adding up monthly fuel burning data from the air pollution control districts as described in Appendix A2 to this study. An important portion of the air quality modeling emission inventory has been confirmed.

Hydroelectric generation within the air basin occurs from DWP operations at the Castaic pumped storage reservoir. Data on operations at Castaic were obtained from the DWP's 10-year summary of operations (Department of Water and Power, 1975b).

## A3.4 End Use Energy Consumption

Energy consumption patterns in the South Coast Air Basin are outlined for the year 1973 in Table A3.6. The term "energy consumption", as used here, has a very narrow meaning. The upper portion of Table A3.6 shows those energy resources which are actually expended for their heating value by their final customer within the air basin. Energy-bearing products, such as asphalt, which are consumed as a raw material instead of for their heating value are noted at the bottom of that table. Energy resources consumed while generating electricity

# TABLE A3.6

## South Coast Air Basin End Uses of Energy Resources-1973

## (in $10^{12}$ BTU's/year)

| | Electricity | Natural Gas | Crude and Unfinished Oils | NGL | LPG | Gasoline Including Aviation Gasoline | Jet Fuel | Light and Middle Distillate Fuel Oil | Residual and Heavy Distillate Fuel Oil | Petroleum Coke | Lubricants | Asphalt | Other Hydrocarbons | Coal | Digester Gas |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CONSUMED IN BASIN AS ENERGY RESOURCE | | | | | | | | | | | | | | | |
| System uses; losses | 28.8 | 20.5 | | | | | | | | | | | | | |
| Residential/commercial | 133.8 | 431.4 | | | 6.6 | | | 8.1 | 8.1 | | | | | 0.2 | |
| Industrial (other than refinery) | 71.2 | 153.9 | | | 1.0 | | | 15.6 | 19.5 | | | | | 57.2 | 2.3 |
| Transportation (civilian) | | | | | | | | | | | | | | | |
| Motor vehicles | | | | | 1.9 | 649.8 | | 42.9 | | | | | | | |
| Aircraft | | | | | | 0.5 | 17.3 | | | | | | | | |
| Railroads | | | | | | | | 10.7 | 0.1 | | | | | | |
| Ships | | | | | | | | 6.3 | 9.0 | | | | | | |
| Military | | | | | | 2.2 | 6.1 | 6.5 | 0.1 | | | | | | |
| Miscellaneous | 21.9 | 8.7 | | | 3.0 | | | 14.5 | 0.6 | | | | | | |
| Subtotal (energy dissipated) | 255.7 | 614.5 | | | 12.5 | 652.5 | 23.4 | 104.6 | 37.4 | | | | | 57.4 | 2.3 |
| CONSUMED AS A RAW MATERIAL[a] | | 18.6 | | | 8.4 | | | | | pass through coke calcining process | to be determined by difference between known sources and exports | | | | |

[a]Or put to other non-energy resource use.

for resale or refining petroleum products for resale are excluded since they have been discussed previously as part of the energy transformation process. In addition, only those fuels sold to transportation vehicles which are actually burned within the mixed layer of the air basin will be considered as "consumed" within the air basin. Fuels leaving the basin in ship bunkers and aircraft fuel tanks will be considered later as "exports" once those vehicles have departed the air basin.

The following discussion is generally organized by the type of fuel involved. However, estimation of fuel use by the military poses some special problems which are best presented in a single discussion. Therefore estimation of military uses of all fuels will be postponed until the end of this section of the energy balance.

### A3.4.1 Natural Gas Consumption

Natural gas sales data for the South Coast Air Basin were obtained from reports furnished to the California Air Resources Board (Wood, 1977) by the gas utilities serving the basin. Data from this source were in good agreement with the 1975 California Gas Report, but were considerably more detailed.

Data for 1974 were the most complete,showing sales to residential, commercial and industrial customers in the basin by both the Southern California Gas Company (the retail arm of Pacific Lighting Companies in the area) plus the gas utility of the City of Long Beach. For 1973, complete data were available from Long Beach, but only total firm and non-refinery interruptible sales were obtained for the

Southern California Gas Company service area. Therefore 1973 Southern California Gas Company sales in both firm and interruptible categories were apportioned among residential, commercial and industrial customers using the same proportions as apparent in their 1974 sales data. The industrial gas quantities shown in Table A3.6 include both firm and interruptible gas combustion by industries other than oil refineries. This should not be confused with the "industrial interruptible" gas total given in the 1975 California Gas Report.

Current feedstock use of natural gas in Southern California was reported by the California Public Utilities Commission (1975). It was assumed that all such use was in the South Coast Air Basin and that the magnitude given for 1975 would apply reasonably well to the year 1973. An amount of natural gas equal to this feedstock use was subtracted from total deliveries to industrial customers, and was then assigned to the raw materials use category. The remaining non-refinery industrial gas deliveries were assumed to be burned for fuel.

Natural gas deliveries classified as "special producer exchange and payback" and "oil company exchange and payback" in the 1975 California Gas Report were totaled. Then these exchange gas volumes were added to gas utility retail sales to South Coast Air Basin refineries as reported by the Southern California Gas Company and the City of Long Beach (Wood, 1977). Total natural gas combustion at South Coast Air Basin refineries was outlined in Table A3.4. Known gas combustion at refineries was subtracted from the available exchange gas plus refinery retail gas purchases. The remainder of the

available exchange gas was assigned to the Miscellaneous Fuel category. Some of this exchange gas was delivered to non-refinery petroleum company operations and may have been burned to generate heat used to stimulate production in old oil fields. Other exchange gas may have gone into feedstock use. Data needed to more clearly define the appropriate sector for use of this exchange gas is unavailable to us.

Additional quantities of natural gas are consumed as part of the gas distribution systems' operation. These system uses and losses are taken from the unaccounted for net inventory change and fuel use totals given for the Southern California Gas Company and the City of Long Beach in the 1975 California Gas Report.

### A3.4.2 Electricity End Use Consumption

Data on electricity uses within the City of Los Angeles were obtained from the DWP's 1975 ten-year statistical report (Department of Water and Power, 1975b). FPC annual statistics on publicly owned utilities (Federal Power Commission, 1972b, 1973b, 1974b) were used to detail electricity use for Pasadena, Burbank and Glendale through the end of the 1973-74 fiscal year. Fiscal year data were converted to a calendar year basis using the procedures discussed previously when explaining Table A3.3.

Electricity use by sector within the SCE system was obtained from their annual reports. These data covered the entire SCE system and not just the South Coast Air Basin. To scale SCE's electricity sales down to the South Coast Air Basin, the basin was compared to

the total SCE service area using county by county statistics from the California Statistical Abstract (California, State of, 1974). It was estimated that the in-basin portion of SCE's service area contained 92% of SCE's total population served, 98% of its manufacturing customers, and 98% of the industrial employees within its service territory. Therefore, it was assumed that 92% of SCE's residential, commercial and "other" (principally municipal) sales, and 98% of their industrial sales could be assigned to the basin. Sales classified as agricultural, municipal or "other" were assigned to the miscellaneous sector of the energy balance.

All electric utilities report some sales for resale. These sales have been apportioned emong consuming sectors by the following methods. About 35% of SCE's sales for resale are delivered to the City of Vernon (Southern California Edison, 1972b), which is a heavily industrial area. Thus one third of SCE's total sales for resale were assigned to industrial activities in Vernon. The remainder of SCE's sales for resale plus the sales for resale by other utilities were divided among all the consuming sectors in proportion to total in-basin direct sales by sector for all participating utilities.

### A3.4.3 Petroleum Product Consumption

#### A3.4.3.1 Motor Vehicle Gasoline

Sales of motor gasoline in California are given by the Ethyl Corporation (1974) for both regular and premium grades. California gasoline sales in 1973 are also listed by the Bureau of Mines (1975e). The Bureau of Mines data show slightly higher motor

gasoline sales than given by Ethyl Corporation. That is not too surprising since Ethyl Corporation describes their data base as representing "oil refiners manufacturing over 95% of the U.S. requirements" for motor gasoline. In this study, Bureau of Mines data will be used to estimate total motor gasoline sales in California. The ratio of premium grade to regular grade sales will be taken from the Ethyl Corporation survey.

Fifty percent of the State's population resides in the South Coast Air Basin. Therefore 50% of the State's total sales of motor gasoline in 1973 were assigned to the South Coast Air Basin. A portion of these gasoline sales were allocated to military uses as will be discussed shortly. The remainder of the total was assigned to consumption by the civilian transportation sector. It was assumed that a net balance exists between gasoline arriving in vehicle fuel tanks and gasoline leaving in the fuel tanks of cars and trucks departing the boundaries of the South Coast Air Basin.

A3.4.3.2 Jet Fuel and Aviation Gasoline End Use Consumption

The Federal Aviation Administration (1973a, 1974a) reports yearly activity at airports having a FAA-operated control tower. These data are reported as "operations" by air carriers, air taxis, general aviation aircraft and military aircraft. An "operation" is either a landing or a take-off. Civilian aircraft operations will be discussed here, while an accounting of military aircraft operations at civilian airports will be postponed until the military fuel use section of this study.

FAA yearly activity reports are compiled on a fiscal year basis. In order to construct calendar year 1973 air traffic estimates, data from FY73 and FY74 were averaged. An additional adjustment to the FAA data is needed to account for a number of small airports in the basin which are without an FAA-operated control tower. A summary of operations at three such independently operated airports was obtained from conversations with airport personnel (Compton Airport Personnel, 1976; Whiteman Airport Personnel, 1976; San Fernando Airport Personnel, 1976). Rough estimates of traffic at the remaining small airports were then made. The total number of operations estimated for non-FAA airports was found to be about 10% of the total general aviation operations at FAA-controlled airports. All operations at these smaller airports were assumed to be in the general aviation category. Thus the number of general aviation operations reported for FAA airports was increased by 10% to achieve a basin-wide total for both FAA and non-FAA airports.

The Environmental Protection Agency (1973) has published data on fuel use per landing and take-off cycle (LTO) for various engine and aircraft types. A landing and take-off cycle represents all fuel used by an aircraft from its descent below an altitude of 3,500 feet through its landing, ground operations, take-off, and subsequent climb to an altitude of 3,500 feet. There are thus two FAA reported operations for every landing and takeoff cycle.

Aircraft fuel consumed in the basin was computed from the EPA landing and takeoff cycle data plus the following assumptions. All

general aviation aircraft were assumed to have one engine, and its fuel use was taken to be the average of use reported for a Teledyne and a Lycoming engine. For air taxis, it was assumed that 30% had one piston engine, 65% had two piston engines and 5% had one turbo-prop engine. Fuel use by air carriers is given for jumbo jets, long-range jets (707 or DC-8), and medium range jets. It was assumed that all air carrier operations at airports other than Los Angeles International (LAX) and Ontario were medium range jets. This assumption was confirmed for Orange County Airport (Orange County Airport Personnel, 1976) and is thus probably true of other small regional airports. The distribution of aircraft types using Ontario airport was obtained by communication with personnel at that airport (Ontario Airport Personnel, 1976). The Department of Airports (1976) of the City of Los Angeles provided an air carrier operations breakdown by aircraft type for LAX in the year 1975. A similar distribution of airport operations by aircraft type was available for 1970 at LAX (Los Angeles Air Pollution Control District, 1971). The percentage distribution of air carrier traffic between jumbo, long range and medium range jets was obtained for 1973 by linear interpolation between the available data sets. For the purpose of computing fuel use by air carriers, it was further assumed that there were an average of 4 engines per jumbo jet, 4 engines per long range jet, and 2.6 engines per medium range jet.

A3.4.3.3 Residual and Distillate Fuel Oil End Use Consumption

Sales of both residual and distillate oil in the State of California in 1973 are reported in the Fuel Oil Sales, Annual series of the Bureau of Mines (1974h). Data from this source are classified into sales for "heating", industrial use (with oil company use listed separately), railroads, ship bunkering, on and off-highway diesel vehicles, plus military, utility and miscellaneous uses. These data were used to construct fuel oil consumption estimates for the residential/commercial, industrial, civilian transportation and miscellaneous sectors of the energy balance. Fuel oils used by oil refineries and utilities have been discussed previously and military fuel oil consumption will be treated at a later point in this survey. As was the case with our previous discussion of energy sources, kerosene use has been lumped with light and middle distillate fuel oil consumption. Also, in line with our attempt to include heavy distillate oil along with residual oil, any Grade 4 fuel oil sales which were explicitly detailed in the Bureau of Mines data base were transferred from the distillate oils category to form a residual plus heavy distillate oil category.

Adequate statistics upon which to base a division of total California oil use between the South Coast Air Basin and the rest of the state seem unavailable. Likewise, separation of fuel oil use into residential, commercial and industrial categories must proceed on the basis of partially supported assumptions. At the state level, it will be assumed that the Bureau of Mines "heating oil" use represents

oil used solely by residential, commercial and institutional customers. Oil listed as "industrial use (excluding oil company use)" will be assumed to provide both industrial process heat and any incidental space heating at non-petroleum industry industrial sites. It may well be the case that some "heating" oils are also consumed by industry, but we have no data from which to estimate how large that fraction might be.

The Stanford Research Institute (1973) study allocates 40% of the state's residential and commercial oil use and 64% of "industrial" oil use to Southern California.* Using county population data from the California Statistical Abstract (California, State of, 1974). it was determined that the South Coast Air Basin has approximately 83% of the population of Southern California. Thus 33% (i.e. 0.40 x 0.83 = 0.33) of the state total "heating oils" use was assigned to the South Coast Air Basin's residential and commercial fuel use sector.

Fuel oil is burned by industry when natural gas supplies have been interrupted. On the basis of Southern California Gas Company industrial gas sales data provided for each air basin in Southern California (Wood, 1977), plus San Diego Gas and Electric and Long Beach City gas system data given in the 1975 California Gas Report, it was estimated that 75% of the non-refinery industrial heating demand in Southern

*By SRI's definition, Southern California is that part of the state not served by PG&E.

California was in the South Coast Air Basin. Therefore, it was assumed that industrial oil use in the South Coast Air Basin by facilities other than oil refineries could be taken as 48%, (i.e. 0.64 x 0.75 = 0.48) of California "industrial oil use (excluding oil company use)" as given by the Bureau of Mines (1974h).

Estimates of industrial fuel oil consumption at refineries in the South Coast Air Basin were entered into the energy balance during our previous discussion of the energy transformation sector.

The Bureau of Mines' (1974h) Fuel Oil Sales, Annual series reports miscellaneous uses of distillate and residual fuel oil, including on-highway and off-highway diesel oil use. On-highway diesel fuel use will be assigned to the transportation sector.

On the basis of truck registration data, which are reported by county for 1972 in the 1974 California County Factbook (Carey, 1974), it was found that about 40% of the State's trucks were registered in the South Coast Air Basin. Therefore, 40% of the State's on-highway diesel fuel used was assigned to the South Coast Air Basin.

All other miscellaneous oil uses (including off-highway diesel oil use) reported by the Bureau of Mines (1974h) will be placed in the Miscellaneous Consumption sector of the energy balance. On the basis of the ratio of basin population to the State's population, 50% of such miscellaneous oil use in California was assigned to the South Coast Air Basin in 1973.

Consumption of fuel oil sold to railroads was assumed to be proportional to track mileage. Railroad track mileage in the South

Coast Air Basin was measured on United States Geological Survey 7-1/2 minute topographic maps and was estimated as 1842.3 miles. A total California track mileage of 8,446 miles was obtained from the Federal Railway Administration (1976). Track mileage in the basin is thus estimated to be 21.6% of the state total. Therefore, 21.6% of the fuel oil sales to railroads in California, as reported by the Bureau of Mines (1974h), were apportioned to consumption within the South Coast Air Basin.

Fuel oil consumed by ships can be divided into three modes of ship operation: dockside use, use while under way inside the port area and near the port entrance, and use while under way in the shipping lanes which parallel the shoreline of the South Coast Air Basin. Each of these modes of operation will be discussed separately. The methodology employed to estimate fuel oil use is based on EPA's Guide for Compiling a Comprehensive Emission Inventory (Environmental Protection Agency, 1972).

Computation of dockside fuel use generally followed the EPA's suggested method. The number of vessels entering each port in the air basin was obtained from Waterborne Commerce of the United States (Corps of Engineers, 1973). It was assumed that only vessels with draft greater than eighteen feet burned fuel while docked in port. Fuel consumption was taken as 660 gallons per vessel per day for distillate oil users and 1900 gallons per day for residual oil users. EPA's suggested assumption of an average three days of dockside fuel burning per vessel arrival was checked against the total number of vessels entering Long Beach and Los Angeles Harbors yearly, and the daily report of vessels in the harbor ("Ship Movements", 1973-1976).

An average dockside retention time of three days was found to be a reasonable estimate. In order to compute dockside fuel use, the total vessel population must be separated into distillate and residual fuel oil users. This was done on the basis of the relative proportion of residual oil to distillate oil sales for bunker fuel in the Los Angeles area. Data on bunker fuel sales to ships engaged in foreign commerce are given by the Bureau of the Census (1974). The Los Angeles Customs District was found to account for 77.4% of the residual oil and 69.8% of the distillate oil sold at California ports to vessels engaged in foreign commerce. These fractions of the California foreign trade total were used to scale California sales of bunker fuel for all purposes, as reported by the Bureau of Mines (1974h), down to the South Coast Air Basin level. The ratio of distillate oil fueled ships to residual oil fueled ships in the harbor was next obtained from estimated bunker fuel sales after weighting the sales data to reflect the lower fuel consumption rate of the smaller distillate fueled ships.

At Los Angeles and Long Beach Harbors, areas inside the breakwater were added to a port entrance zone in order to create a transition area between fuel use at the docks and fuel use in the shipping lanes. From shipping lane maps, it was estimated that an approach distance of 20 miles would be considered as within the port and its entrance zone for each vessel entering that port. For vessels with less than an eighteen foot draft, fuel used in transiting that zone was calculated at the rate prescribed for distillate oil users by

the Environmental Protection Agency (1972). Vessels with greater than 18 foot draft were assumed to enter and leave the port under power of two tugboats, each with a fuel consumption rate the same as that for vessels with less than 18 foot draft. An additional 4000 distillate-fueled vessels per year with less than 18 foot drafts were added to the traffic through the port and its entrance areas as an estimate of the domestic fishing fleet traffic which is not included in the waterborne commerce reports of the Corps of Engineers (1973).

The length of the coastal shipping lanes which parallel the shore of the South Coast Air Basin was measured from the National Oceanic and Atmospheric Administration's West Coast California-San Diego to Santa Rose Island map (undated). The number of ships transiting the shipping lanes in each direction was determined from a sampling of "Ship Movements" reports (1973-1976). Those reports list the origin and destination of ships arriving in and departing from Los Angeles area harbors. Fuel consumption per vessel-mile was taken from data presented by the Environmental Protection Agency (1972). Ships with drafts of 18 feet or less were assigned to distillate oil use. Larger ships were divided between distillate and residual oil use in the same proportions as described for dockside fuel use.

A3.4.3.4 Petroleum Coke Consumption

In view of the high sulfur content of petroleum coke, it is doubtful that any is burned for fuel legally in the South Coast

Air Basin. Therefore, use of petroleum coke as a fuel will be neglected. Petroleum coke is also used as a feedstock by the petroleum coke calcining industry. However, it appears that most calcined petroleum coke is subsequently exported from the basin. Net consumption of petroleum coke within the South Coast Air Basin will be neglected.

A3.4.3.5 Asphalt, Lubricants and Other Hydrocarbons

Asphalt, lubricants and other hydrocarbons are used as industrial raw materials or are put to other non-combustion related uses. Since they are not burned as fuel, their sulfur oxides emission potential is low and their fate will not be explored extensively. Use of these non-fuel petroleum products will be later estimated by difference between refinery production and net harbor exports of such materials.

A3.4.4 Liquified Petroleum Gas and Natural Gas Liquids End Use Consumption

The Bureau of Mines series Liquified Petroleum Gas Sales, Annual (Bureau of Mines, 1974i) lists sales of LPG in California for residential and commercial, industrial, internal combustion, miscellaneous and utility uses. Thirty-three percent of the residential and commercial LPG use in the state was assigned to the South Coast Air Basin on the same basis as developed when discussing residential and commercial heating oil use. Fifty percent of the internal combustion and miscellaneous uses were allocated to the basin on the basis of the ratio of basin population to total state population. These

internal combustion uses were assigned to the transportation sector of the energy balance; however, LPG use in stationary engines is also possible. The 1975 California Gas Report shows no use of LPG as a standby supply for gas utilities in the Los Angeles area in 1973. Therefore, no LPG from the state total for utility use was assigned to the South Coast Air Basin in that year.

The industrial category being considered in the end use consumption sector of this energy balance excludes fuel use by oil refineries. Therefore, use of LPG as a refinery fuel must be separated from the Bureau of Mines data including all industrial uses. This is difficult to accomplish because locally available refinery fuel data lump still gas use with LPG-LRG use. Therefore, a means other than use of the Bureau of Mines data was sought for estimation of non-refinery industrial LPG consumption. On the basis of information gathered during the industrial fuel use survey of Appendix A2 to this report, it was found that only about $0.53 \times 10^{12}$ BTU's per year of LPG were used for fuel by major non-refinery industrial interruptible gas customers within a 50 by 50 mile square laid over the center of metropolitan Los Angeles and Orange Counties. Therefore, it will be assumed that non-refinery industrial fuel uses of LPG in the entire South Coast Air Basin amounted to about $1 \times 10^{12}$ BTU's per year in 1973, rounded up to one significant figure.

Sales of liquified petroleum gases and ethane for petrochemical feedstocks in 1973 are reported by the Bureau of Mines (1974i). Data given are for the entire west coast region of the United States, with each State's feedstock total concealed in order to make it

difficult to estimate chemical feedstock use (a trade secret). For lack of any better scale factor, LPG and ethane use as a raw material will be scaled to the South Coast Air Basin from the west coast total in proportion to the fraction of west coast crude oil and net unfinished oils supplied to the South Coast Air Basin refineries, as given in Table A3.4 Ethane has been separated from LPG (propane and butane) in our classification scheme and is included within the "other hydrocarbons" category of the energy balance.

Natural gasoline and other natural gas liquids are primarily used as a feedstock material for petroleum and chemical processes. Their direct use as a fuel in the South Coast Air Basin is assumed to be zero. Since estimated refinery feedstock use of natural gasoline about equals the South Coast Air Basin's estimated supply, no further sinks for natural gasoline will be sought.

### A3.4.5 Coal Utilization

The coal supplied to the South Coast Air Basin in 1973 was outlined in detail in the energy sources section of this energy balance. Waterborne commerce data on South Coast Air Basin coal shipments for that year (Corps of Engineers, 1973) show negligible coal exports in 1973. Therefore, we will assume that all coal brought into the South Coast Air Basin for use in gas and coke production was consumed within the basin's industrial sector in 1973. The small amount of coal imported for retail sale will be assumed to be burned in the residential/commercial sector.

### A3.4.6 Digester Gas Consumption

Digester gas supplied to electric utilities was outlined in the energy transformation section of this survey. At least one Los Angeles area refinery occasionally receives digester gas for fuel, but air pollution control district records show little actual refinery use of digester gas in 1973. The difference between digester gas production and sales to refineries and utilities represents digester gas combustion at sewage treatment plants. Much of this digester gas performs useful work while powering sewage treatment plant equipment. Excess digester gas is flared.

### A3.4.7 Military Fuel Consumption

Fuel consumption by military activities in the basin is difficult to determine. The results reported here are subject to considerable uncertainty. However, data do seem sufficient to indicate that energy consumption in the basin's military sector is relatively small for all uses except aviation and marine fuels. Therefore, effort needed to characterize fuel use precisely was expended only for aviation and marine refueling operations.

Fuel combustion in 1974 by stationary sources at March and Norton Air Force Bases was obtained from the regional office of the Environmental Protection Agency (Rhea, 1976). The principal fuel burned was natural gas. Since stationary source fuel burning data on several large military installations in the basin were unavailable from EPA, it was decided that no attempt would be made to unbundle military natural gas and electricity use from the totals given in the

basin's residential/commercial, industrial and miscellaneous energy use categories.

The Bureau of Mines (1974h) reports yearly "sales" by state of distillate and residual oil for military use. These data include oil which the military imports into the state for its own use. The largest single use of distillate oil in the civilian sector was seen to be for on- and off-highway vehicle fuel. Therefore, it was assumed that military distillate oil should be apportioned to the South Coast Air Basin in a manner consistent with likely vehicle use patterns. Military distillate fuel use in the South Coast Air Basin was scaled from the state totals in proportion to the fractions of the State's total military personnel at work in the basin as given by the 1970 census.

The 1970 Census of Population for California places total armed forces strength in California at about 346 thousand persons in 1970 (Bureau of the Census, 1973a; difference between total state labor force and civilian labor force). The special report on Journey to Work of the 1970 Census of Population (Bureau of the Census, 1973b) places armed forces personnel working in Ventura, Orange, Los Angeles Riverside and San Bernardino Counties at 69 thousand persons in 1970. These county totals unfortunately include portions of Los Angeles, Riverside and San Bernardino Counties which lie in the desert outside of the air basin. Data are not readily available which permit subtraction of military personnel based in the desert from those county totals. However, two other factors serve to reduce the amount

by which the 69,000 person armed forces total for those counties might overestimate military personnel working in the South Coast Air Basin. First, there are a number of persons in the armed forces living in these counties who were not included in the totals for those working within the county limits because they did not report their place of assignment to the census takers. Secondly, none of the military personnel stationed in Santa Barbara County were included in the previous local totals because the vast majority of Santa Barbara County military personnel are assigned to areas outside of the South Coast Air Basin boundaries. It is judged that the 69 thousand persons total obtained from the five-county summation is a reasonable estimate of armed forces personnel working in the South Coast Air Basin in 1970. That estimate implies that the air basin contained about 20% of the military personnel working in the state at the time of the last census. Thus, 20% of the distillate oil used by the military in California in 1973 was apportioned to the South Coast Air Basin.

The principal use of residual oil by the military in California was assumed to be for bunkering of Naval vessels. Personnel at the Long Beach naval station's fuel depot were contacted. They indicated that a significant amount of a residual type oil referred to as Navy Special grade was loaded aboard naval vessels at Long Beach in 1973. However, heavy oil bunkering of naval vessels at Long Beach has since ceased, and personnel familiar with the details of the 1973 operations were not available for interview. When pressed to make an estimate for 1973, personnel at the fuel depot said that a guess that Long Beach accounted for 20% of California naval fuel bunkering in 1973

would be reasonable. That estimate coincided very closely with the fraction of California military personnel at work in the basin. Therefore, 20% of the California residual fuel use by the military was assigned to the South Coast Air Basin in 1973. Our previous estimate of residual oil burned by civilian ships in the South Coast Air Basin was compared to fuel loaded aboard civilian ships as deduced in the forthcoming export section of this energy balance. It was found that residual fuel oil burned by ships within the air basin and offshore shipping lanes totaled about 10% of residual oil bunker fuel sales to those ships from basin fuel depots. Therefore residual oil burned by naval ships in the South Coast Air Basin was taken as 2% (i.e. 10% of 20%) of total California uses of residual fuel oil by the military. Most of the residual oil loaded aboard naval ships in the South Coast Air Basin will be shipped out of the basin in vessel fuel tanks, as detailed in the forthcoming export section of this energy balance.

Total domestic motor gasoline procurement by the military in 1972 is given by Mutch (1973). This level of total domestic use was assumed to hold for 1973 as well. It was next assumed that California military gasoline consumption constituted the same fraction of total domestic military gasoline use as was apparent from the ratio of California to total United States domestic military distillate oil use given by the Bureau of Mines (1974h). Then 20% of the military motor vehicle gasoline sales total constructed for the State of California was assigned to the South Coast Air Basin on the same basis as discussed previously for distillate oils.

Military and civilian air traffic at military airports is reported periodically by the Federal Aviation Administration (FAA). The closest reporting period to 1973 was for calendar year 1974 (Federal Aviation Administration, 1974b). Military air traffic at South Coast Air Basin civilian airports in 1973 and 1974 was determined from the previously described documents on flight operations at airports with FAA-operated control towers (Federal Aviation Administration, 1973a, 1974a). Then aircraft operations at military airports in 1974 (Federal Aviation Administration, 1974b) were scaled to 1973 using the ratio of 1973 to 1974 military operations apparent at the civilian airports for which data for both years were available. Military and civilian operations at military airports were added to military operations at FAA-operated airports to obtain a 1973 South Coast Air Basin total for military-related air traffic.

The Federal Aviation Administration (1976) was able to provide a description of the different types of aircraft in use by the military at bases in the South Coast Air Basin. Flight operations at each air field were then distributed among these aircraft types in what seemed to be a reasonable, although arbitrary manner. Fuel consumption during operations below 3500 feet in altitude was then computed using the same procedures as for civilian aircraft.

### A3.5 Exports

A summary of energy resource exports from the South Coast Air Basin for the year 1973 is given in Table A3.7. Fuels are exported from the basin by a number of methods. Pipelines carry natural gas to nearby service areas. Petroleum products are piped

TABLE A3.7

South Coast Air Basin Energy Exports-1973

| | $10^{12}$ BTU/year |
|---|---|
| Natural Gas | |
| Out-of-basin sales to | |
| Pacific Lighting customers | 90.2 |
| Sales to San Diego Gas & Electric | 91.2 |
| Exchange with out-of-basin utility | 5.4 |
| Subtotal | 181.6 |
| Crude Oil - Net | |
| Los Angeles and Ventura oil shipped to sea less estimated return flows of that oil at other South Coast Air Basin ports | 57.5 |
| Petroleum Product Exports | |
| Harbor exports | |
| Gasoline | 47.9 |
| Jet fuel | 17.4 |
| Distillate oil and kerosene | 89.7 |
| Residual oil | 155.1 |
| Petroleum coke | 109.4 |
| Lubricants and greases | 20.0 |
| Asphalt and asphalt materials | 16.5 |
| LPG | 0.2 |
| Other | 5.1 |
| Subtotal | 461.3 |
| Overland transport | |
| Arizona and southern Nevada | |
| Gasoline | 90.5 |
| Jet fuel | 21.8 |
| Light & middle distillate oil | 52.9 |
| Residual oil | 27.9 |
| Inland to southern California | |
| Gasoline | 104.2 |
| Subtotal | 297.3 |
| Exported in transport mode fuel tanks | |
| Transportation (civilian) | |
| Aviation gasoline | 3.8 |
| Jet fuel | 100.2 |
| Distillate bunker fuel | 2.7 |
| Residual bunker fuel | 84.7 |
| Military | |
| Aviation gasoline | ∿0 |
| Jet fuel | 11.3 |
| Residual bunker fuel | 1.3 |
| Subtotal | 204.0 |
| TOTAL INVENTORIED EXPORTS | 1,201.7 |

to Arizona, Nevada and San Diego. Crude oil and refined petroleum products are exported from local harbors, and other liquid fuels leave the air basin in the tanks of ships and aircraft. It is likely that significant quantities of petroleum products are shipped overland by pipeline, tank car and tank truck to other areas of California. With the exception of gasoline, these overland exports are difficult to quantify and will be neglected. Hence, the total exports identified in the energy balance tabulations of Table A3.7 are likely to be below actual export levels.

### A3.5.1 Natural Gas Exports

Exports of natural gas from the basin represent deliveries by the Pacific Lighting Companies to San Diego Gas and Electric and to their own customers in the San Joaquin Valley, South Central Coast, and Southeast Desert Air Basins. Deliveries to San Diego were obtained from the 1975 California Gas Report, while the remaining data came from reports supplied to the California Air Resources Board by local gas utilities (Wood, 1977).

The 1975 California Gas Report also outlines exchange transactions in which California source gas is delivered through the Pacific Lighting System to PG&E. This utility to utility exchange is represented as a net export from the energy supply available to gas utilities serving the South Coast Air Basin.

### A3.5.2 Crude Oil Exports (Net)

The crude oil exports listed in Table A3.7 represent locally produced oil shipped to sea less return flows of that local oil to other South Coast Air Basin ports. These net exports were determined from data presented in Appendix A1 to this survey. Total Los Angeles and Ventura area crude oil remaining in the basin as given in Table A1.10 was subtracted from Los Angeles and Ventura area crude oil production given in Table A1.6 to obtain an estimate of net crude oil exports.

### A3.5.3 Refined Petroleum Products Exported by Ship

Data on exports of refined petroleum products from local harbors were obtained from Waterborne Commerce of the United States (Corps of Engineers, 1973). Where the direction of flow was not indicated, refined products were assumed to be shipped to sea from El Segundo and received at Huntington Beach, Ventura, Port Hueneme and Carpenteria. In cases where a product classification used by the Corps of Engineers encompassed more than one product type, the entire energy content of imports in that classification was assigned to the most prominant product in the group.

### A3.5.4 Refined Petroleum Products Exported by Overland Transport

Shipments of California refinery products to Arizona and Nevada are reported for 1974 by the California Energy Planning Council (1974). Lacking additional data, these exports were assumed to represent 1973 as well. All fuel sent to Arizona and to the Las Vegas area was assumed to come from South Coast Air Basin refineries.

From population distribution data for the Reno and Las Vegas areas (Rand McNally, 1973), it was estimated that Southern Nevada surrounding Las Vegas constituted 68.9% of that state's population. Therefore, all of Arizona's and 68.9% of Nevada's refined petroleum product imports from California were taken to be exported overland from Los Angeles.

By examination of port records for San Diego, it was observed that relatively little gasoline was received in that location by ship. Review of pipeline maps given by McCaslin (1974), shows a refined product pipeline proceeding from Los Angeles to the San Diego area. It was therefore considered likely that most of the gasoline needs of Southern California outside of the South Coast Air Basin were being met by overland shipments from Los Angeles. While data on intrastate refined product pipeline, tank car, and tank truck transportation are unavailable to us, it should be possible to estimate gasoline demand in the remainder of Southern California on the basis of population served. County population statistics given in the California Statistical Abstract (California, State of, 1974) were reviewed. It was concluded that between 8% and 12% of California's population lay in areas of Southern California outside of the South Coast Air Basin which were probably supplied with gasoline from the stocks available in Los Angeles. Since some transport of gasoline to San Diego by ship appears to occur, our estimate for the fraction of California's population supplied with gasoline by overland transport from Los Angeles refineries will be

held to the low side of the above population range. Therefore 8% of California's total gasoline production, as given in Table A3.4 was assigned to overland export to other parts of California from the Los Angeles basin.

Estimation of overland export of other refined petroleum products to Southern California areas outside of the South Coast Air Basin will not be attempted. There are substantial receipts of fuel oils at San Diego County harbors which would indicate that much of the fuel oil supply exported from Los Angeles to other parts of the state has already been counted when we outlined waterborne exports. Unless a detailed energy balance were performed on San Diego, an overland transport estimate for fuel oils based on population alone would run a significant risk of double counting much of the fuel oil which appears to move in waterborne commerce. Because of the lack of this intrastate overland export estimate, most petroleum categories in the energy "balance" are expected to show a slight net surplus of products for which the ultimate consumer is unknown.

### A3.5.5 Fuels Exported in the Tanks of Transportation Vehicles

Long range transportation vehicles (ships and airplanes) carry fuel supplies in their tanks which are far in excess of that burned while in the vicinity of their refueling terminals. Jet fuel and bunker fuel sales exceed combustion within the confines of the South Coast Air Basin. This difference represents a net fuel export from the air basin's energy economy.

Estimation of residual and distillate fuel oil sales for ship bunkering was described briefly during our previous discussion of fuel combustion by ships. Distillate and residual fuel oils sold in California for civilian ship bunkering (Bureau of Mines, 1974h) were apportioned to the South Coast Air Basin in proportion to the Los Angeles Customs District's fraction of total California sales of each of these fuels to ships engaged in foreign commerce (Bureau of the Census, 1974). Then net exports of fuel contained in ship bunkers were obtained by subtracting our previous in-basin fuel combustion estimates for ships from total bunkering sales of each oil type.

In a previous discussion of military oil use, it was estimated that naval bunkering at Los Angeles and Long Beach harbors in 1973 accounted for 20% of total California residual oil "sales" to the military as given by the Bureau of Mines (1974h). Our fuel combustion estimate for naval ships was subtracted from our estimate of bunker fuel supplied to the military in the South Coast Air Basin to obtain a net estimate for naval bunker fuel exported from the South Coast Air Basin in ship fuel tanks.

Total demand for aviation gasoline and jet fuel in the West Coast district of the United States (PAD District V) is given by the Bureau of Mines (1975e). The Bureau of Mines (1975e) also lists West Coast shipments of aviation fuels for both military and commercial use. Data on total shipments and demand are in reasonable agreement. Therefore, West Coast Aviation gasoline and jet fuel demand figures

were apportioned between military and civilian uses in the relative proportions indicated by shipments of fuels to military and civilian customers.

Federal Aviation Administration (FAA) statistics are available on the number of aircraft operations at civilian and combined use airports on the West Coast of the United States (Federal Aviation Administration, 1973a). From these sources, it was estimated that 26.6% of the West Coast Air Carrier Operations took place at South Coast Air Basin airports. Therefore, 26.6% of the civilian aviation jet fuel sales on the West Coast were assigned to the South Coast Air Basin. In a similar manner, it was found that 34.6% of the air taxi plus general aviation activity on the West Coast took place at South Coast Air Basin airports. Thus 34.6% of West Coast civil aviation gasoline demand was assigned to local airports. From data on military aircraft operations at military airports (Federal Aviation Administration, 1974b) plus military traffic at civilian airports (Federal Aviation Administration, 1973a), it was estimated that 9.1% of the military flight operations in the West Coast region of the United States occurred at South Coast Air Basin airports and military bases. Therefore, 9.1% of West Coast military jet fuel and aviation gasoline supplies were assigned to the South Coast Air Basin. Net fuel exports in the tanks of all aircraft were then determined by difference between South Coast Air Basin aviation fuel demand and our previous estimates of in-basin aviation fuel combustion. About 15% of the civilian jet fuel and about 35% of the

military jet fuel supplied to aircraft at local airports is estimated to be burned within the air basin.

A3.6 The Energy Balance

Table A3.8 summarizes the energy balance on the South Coast Air Basin for the year 1973. A total of nearly 3700 x $10^{12}$ BTU's of energy resources entered the air basin's economy in that year. The ultimate fate of that energy supply is also apparent from Table A3.8.

- 15% of the energy supply is lost in transformation processes such as petroleum refining and electricity generation;
- 48% is expended for its heating value within the air basin by a final consumer of energy products;
- 4% of the energy content of the basin's energy resource base is tied-up in products that are used as industrial raw materials; and
- 33% of the energy supply passing through the air basin's economy is subsequently exported.

If all discrepancies between sources and sinks for various energy products are added regardless of sign, the total discrepancy is less than 5% of the gross energy input to the basin. On an aggregate basis, the energy balance actually balances with less than a 1% net surplus.

The degree to which the energy balance actually balances for individual product types is more variable, but still is considered to be acceptable. Three of the five largest energy flows in the system, (i.e. natural gas, electricity and heavy fuel oil) balance to within less than a 1% discrepancy between sources and sinks. The gasoline

# TABLE A3.8

## South Coast Air Basin Energy Balance--1973
## ($10^{12}$ BTUs per year)

| | Electricity | Natural Gas | Crude and Unfinished Oils | NGL | LPG | Still Gas for Fuel | Gasoline | Jet Fuel | Light and Middle Distillate Fuel Oil | Residual and Heavy Distillate Fuel Oil | Petroleum Coke | Lubri-cants | Asphalt and Road Oil | Other Hydro-carbons | Coal | Digester Gas | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SOURCES | | | | | | | | | | | | | | | | | |
| Resource base: imports plus local crude oil and natural gas production | 97.3 | 1050.3 | 2182.3 | 20.9 | 14.4 | | 69.6 | 4.4 | 83.6 | 127.6 | 5.5 | 12.3 | 0.1 | 4.6 | 57.4 | 2.6 | 3732.9 |
| Adjustments: change in gas storage; out-of-basin electric use | -13.1 | -25.2 | | | | | | | | | | | | | | | -38.3 |
| Subtotal | 84.2 | 1025.1 | 2182.3 | 20.9 | 14.4 | | 69.6 | 4.4 | 83.6 | 127.6 | 5.5 | 12.3 | 0.1 | 4.6 | 57.4 | 2.6 | 3694.6 |
| TRANSFORMATION SECTOR | | | | | | | | | | | | | | | | | |
| Refinery feedstock (-) | | | -2124.8[a] | -23.9 | -8.7 | | | | | | | | | -16.9[b] | | | -2174.3 |
| Refinery fuels (-) | -9.8 | -48.5 | | | | -149.8 | | | | -11.8 | | | | | | | -219.9 |
| Refinery production(+) | | | | | 36.1 | 108.4 | 863.0 | 224.3 | 126.9 | 581.2 | 112.0 | 18.5 | 88.0 | 60.3 | | | 2218.7 |
| Utility fuels (-) | | -160.9 | | | | | | | -2.7 | -386.3 | | | | | | -0.3 | -550.2 |
| Utility production (+) | 179.9 | | | | | | | | | | | | | | | | 179.9 |
| Subtotal | 170.1 | -209.4 | -2124.8 | -23.9 | | -14.0 | 863.0 | 224.3 | 124.2 | 183.1 | 112.0 | 18.5 | 88.0 | 43.4 | | -0.3 | -545.8 |
| CONSUMED IN BASIN AS ENERGY RESOURCE | | | | | | | | | | | | | | | | | |
| System uses; losses | -28.8 | -20.5 | | | | | | | | | | | | | | | -49.3 |
| Residential/commercial | -133.8 | -431.4 | | | -6.6 | | | | -8.1 | -8.1 | | | | | -0.2 | | -588.2 |
| Industrial (other than refinery) | -71.2 | -153.9 | | | -1.0 | | | | -15.6 | -19.5 | | | | | -57.2 | -2.3[a] | -320.7 |
| Transportation (civilian) | | | | | -1.9 | | -650.3 | -17.3 | -59.9 | -9.1 | | | | | | | -738.5 |
| Military | | | | | | | -2.2 | -6.1 | -6.5 | -0.1 | | | | | | | -14.9 |
| Miscellaneous | -21.9 | -8.7 | | | -3.0 | | | | -14.5 | -0.6 | | | | | | | -48.7 |
| Subtotal | -255.7 | -614.5 | | | -12.5 | | -652.5 | -23.4 | -104.6 | -37.4 | | | | | -57.4 | -2.3 | -1760.3 |
| CONSUMED AS A RAW MATERIAL[c] | | -18.6 | | | -8.4 | | | | | | pass through | -10.8[a] | -71.6[a] | -42.9[a] | | | -152.3 |
| EXPORTS | | | | | | | | | | | | | | | | | |
| As a commodity (by ship) | | | -57.5 | | -0.2 | | -47.9 | -17.4 | -89.7 | -155.1 | -109.4 | -20.0 | -16.5 | -5.1 | | | -518.8 |
| As a commodity (overland) | | -186.8[d] | | | | | -194.7 | -21.8 | -52.9 | -27.9 | | | | | | | -484.1 |
| In transport mode fuel tanks | | | | | | | -3.8 | -111.5 | -2.7 | -86.0 | | | | | | | -204.0 |
| Subtotal | | -186.8 | -57.5 | | -0.2 | | -246.4 | -150.7 | -145.3 | -269.0 | -109.4 | -20.0 | -16.5 | -5.1 | | | -1206.9 |
| SUMMARY | | | | | | | | | | | | | | | | | |
| Total sources (+ flows) | 277.2 | 1050.3 | 2182.3 | 20.9 | | 158.9 | 932.6 | 228.7 | 210.5 | 708.8 | 117.5 | 30.8 | 88.1 | 64.9 | 57.4 | 2.6 | |
| Total sinks (- flows) | -278.6 | -1054.5 | -2182.3 | -23.9 | | -179.6 | -898.9 | -174.1 | -252.6 | -704.5 | -109.4 | -30.8 | -88.1 | -64.9 | -57.4 | -2.6 | |
| Absolute difference | -1.4 | -4.2 | (a) | -3.0 | | -20.7 | 33.7 | 54.6 | -42.1 | 4.3 | 8.1 | (a) | (a) | (a) | | (a) | 29.3 |
| Difference as % of sources | -0.51% | -0.40% | (a) | -14.35% | | -13.03% | 3.61% | 23.87% | 20.0% | 0.61% | 6.89% | (a) | (a) | (a) | | (a) | |
| Difference as % of total energy resources | -0.04% | -0.11% | | -0.08% | | -0.56% | 0.91% | 1.48% | -1.14% | 0.12% | 0.22% | | | | | | 0.79% |

Notes: (a) Obtained by difference
(b) May include some natural gas
(c) Or put to other non-energy resource use
(d) Includes exchange with out-of-basin utility

summary balances to within 4% and the crude oil supply balances by virtue of the fact that refinery input was determined by difference between crude oil supply and exports. In addition, the petroleum coke summary balances with only a 7% surplus. That is considered to be good agreement given that petroleum coke production had to be scaled in two stages from a West Coast refinery total. The unaccounted-for petroleum coke may well have been lost in coke calcining processes which have not been investigated for their effect on product "shrinkage".

Major percentage discrepancies between individual product sources and sinks occur in the light and middle distillate fuel oil categories including both jet fuel and light fuel oil. These two product lines share overlapping hydrocarbon boiling ranges. Kerosene heating oil has much the same composition as certain jet and turbine fuels. Our estimated surpluses of jet fuel and deficiency of light and middle distillate heating oil are of corresponding magnitude and opposite sign. These two discrepancies could well be self-cancelling. The source of the estimation error is not readily apparent from the highly aggregated data on refinery output which are at our disposal. For the purpose of the forthcoming sulfur balance, jet fuel and light fuel oils must be merged because available data on refinery sulfur output are given only for both product streams combined. If the source of the jet fuel surplus and light fuel oil deficit lies in the refinery output estimate made for each fuel, that problem alone will not affect the forthcoming sulfur balance's accuracy.

The energy balance also shows an excess of LPG and NGL consumption above known supply. This problem is felt to arise from an inadequate knowledge of the sources of supply for these materials. LPG is the product of natural gas processing plants and refinery processes. Harbor receipts show that negligible quantities of liquified gases were imported into the South Coast Air Basin in 1973 by waterborne commerce. Refinery gas consumption for fuel appears to include virtually all potential local refinery LPG production. Therefore, it seems likely that LPG sufficient to meet residential, commercial, industrial, and feedstock demand may have been imported into the basin by intrastate overland transportation modes. If that were the case, a significant source of LPG supply would not be identifiable in our commerce statistics and would have been omitted from the energy balance. A similar situation is thought to mask NGL supply: it is either included within crude oil statistics, lumped with unidentified hydrocarbons or moved overland within California in a way that does not easily stand out in the intrastate commerce records. Since the sulfur content of LPG and NGL is very low, this discrepancy between LPG and NGL supply and consumption will not jeopardize the forthcoming sulfur balance.

Turning our attention to product supplies and uses, it is seen that crude oil is the principal energy input to the basin, accounting for 59% of the original energy supply. Natural gas is in second place with about 28% of the total energy supply. Imported refined petroleum products and imported electricity follow in order of importance to the gross energy resource base of the basin.

From Tables A3.8 and A3.4 it is seen that estimated refinery feedstocks and gross product yield are in good agreement on a net energy content basis. However, in order to obtain this transformation of feedstocks into products, fuels were consumed with an energy content equal to about 10% of gross refinery product output. The ratio of fuel use to product energy content is about the same for the South Coast Air Basin and for all refineries located in the Western United States. However, South Coast Air Basin refineries appear to depend much more heavily on refinery gases for fuel than is typical of refineries in the West Coast Region (PAD District V) as a whole.

The principal refinery product in the South Coast Air Basin is gasoline, which accounts for 39% of total refinery product output on an energy content basis. The next largest refinery product stream consists of heavy fuel oil. The principal customer for this heavy fuel oil is a second stage of the energy transformation sector: the electric utility industry.

Electric utilities consumed $550.2 \times 10^{12}$ BTU's of fossil fuel within the South Coast Air Basin in 1973. Electricity generated from that fuel consumption amounted to $179.9 \times 10^{12}$ BTU's for an overall conversion efficiency of 33%. Seventy percent of that electricity was generated by combustion of heavy fuel oil. If a typical refinery energy loss of 10% is associated with preparation of the fuel oils used by utilities, then the overall efficiency of generating electricity using liquid petroleum products falls even further.

The largest energy demand in the end use consumption sector is for transportation fuels, principally gasoline. Gasoline accounts for roughly one third of the total energy used in the air basin by final product customers. Residential and commercial customer demand for natural gas is second in magnitude, followed by industrial natural gas use and residential/commercial electricity demand.

Energy exports from the basin consist almost entirely of refinery products, plus natural gas in transit to other parts of the state. Net refinery product exports (i.e. exports less imports) have an energy content equal to about 30% of that of the initial crude oil runs to local refineries. That raises on interesting observation about the nature of trade patterns in the Southwest. For many years, persons living in areas outside of Los Angeles have complained that Los Angeles is exporting air pollution by locating some electric generating stations serving Los Angeles in desert areas to the east of the basin. As can be seen from Table A3.8, 33% of the electricity supply for the South Coast Air Basin comes from sources outside of the basin. From Table A3.2 it is seen that about half of that imported electricity is generated by fossil fuel fired steam plants located outside the air basin. However, it is also now apparent that a fairly large fraction of the emissions caused by petroleum refining in Los Angeles are incurred within the South Coast Air Basin for the benefit of final product customers located elsewhere, principally in San Diego, Arizona and Nevada. It is obvious that the energy economies of all of Southern California, Arizona and Southern Nevada are

so interdependent that the question of "exporting pollution" when siting a major energy transformation facility such as a power plant or refinery becomes nearly meaningless.

## A3.7 An Introduction to the Sulfur Balance

In order to convert the energy balance into a sulfur balance for the South Coast Air Basin, data on the sulfur content of fuels must be combined with a knowledge of industrial process activities. For fuels supplied to combustion sources, a knowledge of the quantity of sulfur in fuels is usually sufficient to completely determine sulfur received and atmospheric sulfur oxides emissions. For certain industrial processes, sulfur enters the facility in a variety of raw materials and leaves the factory in a large number of joint products, plus solid wastes, liquid wastes and atmospheric emissions. In the following sections of this survey, the sulfur content of fuels will first be determined from Bureau of Mines fuel analyses and other sources. Then industrial process data from the detailed emission inventory of Appendix A2 of this study will be combined with the fuel sulfur content information in order to compile the desired sulfur balance on the South Coast Air Basin.

## A3.8 Sulfur Flows Entering the South Coast Air Basin in 1973

The quantities of sulfur accompanying energy resources entering the South Coast Air Basin in 1973 are shown in Table A3.9. Values given in that table are in thousands of pounds of sulfur per day. Comparison of each portion of the sulfur balance (of which Table A3.9 forms a part) to the atmospheric emissions given in

TABLE A3.9

South Coast Air Basin Sulfur Sources-1973

| | 1000 lbs Sulfur per Day |
|---|---|
| Natural Gas | |
| California sources-utility purchase | 0.05 |
| -gas exchange | 0.02 |
| Interstate receipts | 0.73 |
| Purchases from other utilities | 0.01 |
| Less net injection to storage | -0.02 |
| Subtotal | 0.79 |
| Crude and Unfinished Oils | |
| Los Angeles Basin & Ventura area total production, plus South Coast Air Basin receipts from out-of-basin sources | 3,942.5 |
| Petroleum Product Imports | |
| Harbor receipts | |
| Gasoline (including natural gasoline) | 4.40 |
| Jet fuel | 0.31 |
| Distillate oil and kerosene | 29.45 |
| Residual oil | 77.70 |
| Petroleum coke | 16.11 |
| Lubricants and greases | (small) |
| Asphalt and asphalt materials | (small) |
| Other | (probably small) |
| Subtotal | 127.97 |
| Liquid Petroleum Gas | 0.01 |
| Digester Gas | 0.63 |
| Coal | |
| Coking coal | 91.41 |
| Miscellaneous | 0.32 |
| Subtotal | 91.73 |
| Elemental Sulfur (Harbor Receipts) | 0.06 |
| Sulfuric Acid (Harbor Receipts) | 0.00 |
| TOTAL INVENTORIED IMPORTS | 4,163.69 |

TABLE A3.10

Sulfur Content of Fuels

| FUEL | Fuel Sulfur Content (wt% unless otherwise stated) 1972 | 1973 | 1974 | 1000 lbs Sulfur(a) per $10^{12}$ BTUs For Year 1973 | API Gravity | Reference |
|---|---|---|---|---|---|---|
| Gasoline | | | | | | |
| Regular | 0.072 | 0.056 | 0.048 | 27.72 | 59.0 | Bureau of Mines (1972f through 1975f) |
| Premium | 0.042 | 0.037 | 0.050 | 18.37 | 58.5 | Bureau of Mines (1972f through 1975f) |
| Average | 0.057 | 0.047 | 0.049 | 23.10 | | |
| Jet Fuels | | | | | | |
| Jet A Commercial | 0.048 | 0.045 | 0.054 | 22.47 | 42.9 | Bureau of Mines (1973a through 1975a) |
| JP-5 Military | 0.037 | 0.096 | 0.065 | 48.27 | 41.7 | Bureau of Mines (1973a through 1975a) |
| Diesel Transportation Fuels | | | | | | |
| T-T (trucks and trailers) | 0.218 | 0.230 | 0.265 | 116.45 | 36.7 | Bureau of Mines (1972d through 1974d) |
| R-R (railroads) | 0.352 | 0.359 | 0.315 | 184.72 | 34.0 | Bureau of Mines (1972d through 1974d) |
| S-M (stationary and marine) | 0.160 | 0.320 | 0.320 | 165.15 | 33.5 | Bureau of Mines (1972d through 1974d) |
| Fuel Oils | | | | | | |
| Utility light distillate turbine fuel | | 0.05 | | 24.03 | 42.0 | See Appendix A2 |
| #2 Distillate | 0.217 | 0.247 | 0.230 | 126.27 | 34.7 | Bureau of Mines (1972b through 1974b) |
| #6 Residual (high sulfur) | 1.79 | 1.58 | 1.64 | 875.32 | 10.6 | Bureau of Mines (1972b through 1974b) |
| #6 Residual (low sulfur) | 0.40 | 0.40 | 0.40 | 209.23 | 19.0 | See Appendix A2 |
| Power plant residual (low sulfur) | 0.420 | 0.439 | 0.436 | 222.25 | 24.0 | See Appendix A2 |
| Gaseous Fuels | | | | | | |
| Refinery gas | 10(b) | 6(b) | 6(b) | 6.59 | | See Appendix A2 |
| Digester gas | 600(c) | 600(c) | 600(c) | 89.0 | | Estimate (Rojas, 1976) |
| Natural gas | 0.3(d) | 0.3(d) | 0.3(d) | 0.283 | | Environmental Protection Agency (1973) |
| Solid Materials | | | | | | |
| Coal | | 0.7 | | 583.3 | | Bureau of Mines (1975e) |
| Petroleum coke | | 1.61 | | 1069.1 | | Estimate; see text |

(a) Note that $10^3$ lbs sulfur/$10^{12}$ BTU is equivalent to tons of $SO_2$/$10^{12}$ BTU.
(b) In grains per 100 $ft^3$.
(c) In ppm $H_2S$ (digester gas sulfur content varies widely from plant to plant; this is an intermediate value from among a survey of several plants).
(d) in lbs/$10^6$ $ft^3$.

Appendix A2 is facilitated by the fact that combustion of a fuel supply containing one thousand pounds of sulfur per day results in one ton per day of $SO_x$ emissions (stated as $SO_2$). Sulfur flows in Table A3.9 may thus be viewed as potential $SO_x$ emissions in units of short tons per day as $SO_2$.

Sulfur flows into the air basin were determined from the energy balance plus estimates of the sulfur content of fuels. The sulfur content of energy resources consumed in the South Coast Air Basin is shown in Table A3.10. A description of how the sulfur inflows of Table A3.9 were developed from the energy balance follows.

### A3.8.1 Crude and Net Unfinished Oils

In Appendix A1 to this study, the sulfur contained in crude oil entering South Coast Air Basin refineries was estimated for the year 1973. That appendix forms the basis for the sulfur flows in crude-type oils entering the South Coast Air Basin as shown in Table A3.9. Estimates of sulfur contained in all crude oils produced in the Los Angeles and Ventura area oil fields are taken from production data given in Table A1.6. All sulfur accompanying local oil production is entered as a sulfur source in Table A3.9. Sulfur accompanying net out-of-basin shipments of some of this locally produced oil will be subtracted from the sulfur balance later as an export. The sulfur content given for all other crude oil flows represents only the net receipts of sulfur from outside the boundaries of the air basin, not the total sulfur production in the oil fields of origin. Sulfur received in foreign and domestic oil imports is detailed in Table A1.10.

### A3.8.2 Refined Petroleum Product Sulfur Content

The procedure used for determining the inflows of sulfur in each of the refined petroleum product streams was the same for all product types. The weight percent sulfur content of each fuel was determined from Bureau of Mines reports or other records. A representative sulfur content for the year 1973 was entered in Table A3.10. Representative sulfur content data for 1972 and 1974 were also recorded for the sake of comparison. Then the sulfur content per $10^{12}$ BTU's of fuel energy content was computed for each fuel using the energy content data of Table A3.1, the weight percent sulfur data of Table A3.10, and the fuel density implied by the API gravity of the samples from which the sulfur analysis was taken. The results of those calculations are shown in Table A3.10 for the year 1973. Then these sulfur contents per $10^{12}$ BTU's were applied to the energy imports given in Table A3.2 in order to obtain the total flux of sulfur entering the air basin in imported fuels.

A description of the source of the fuel sulfur content data follows, along with notes on any further assumptions which were made.

#### A3.8.2.1 Gasoline Sulfur Content

The sulfur content of gasoline was reported for summer and winter seasons of each year by the Bureau of Mines (1972f through 1975f). Samples are reported for 17 geographic regions of the country, of which Southern California forms one region. Data shown in Table A3.10 were obtained from these Bureau of Mines Southern California

gasoline analyses after having adjusted their seasonal reports to a calendar year basis. Calendar year averages for 1973, for example, are based on the following weighing factors: Winter 1972-73, 25%; Summer 1973, 50%; Winter 1973-74, 25%. A weighted average sulfur content for all gasolines has been calculated using the relative proportions of regular and premium grade sales for California in 1973 as given by Ethyl Corporation (1974).

A3.8.2.2 Jet Fuel Sulfur Content

The sulfur content of jet fuel is reported on an annual basis by the Bureau of Mines (1973a through 1975a). Data for Type A commercial and JP-5 military fuels were used to calculate the sulfur content of jet fuels burned by the civilian transportation and military sectors, respectively. Imported jet fuels entering the basin were treated as being 87% commercial grade and 13% military type, in proportion to the relative quantities of jet fuel delivered locally to each of these customers in 1973 (i.e. burned plus exported in fuel tanks).

A3.8.2.3 Light and Middle Distillate Fuel Oil Sulfur Content

Data on the sulfur content of distillate fuel oil used for residential, commercial and industrial purposes was taken from the Grade 2 fuel oil summary for the Western Region of the United States given by the Bureau of Mines (1973b) in their burner fuel oils series. The sulfur content of diesel fuel used by trucks, railroads, and marine diesel engines is also reported by the Bureau of Mines (1973d). Data given in that source were used to calculate

the sulfur content of distillate fuels used in the transportation sector of the energy balance. Imported distillate fuel oils probably span a variety of grades and uses. This mixed pool of imported distillate oil was characterized as being 23% Grade 2 (all stationary sources), 61% type TT (trucks), 10% type RR (railroad), and 6% type SM (maritime). Those quantities were taken in proportion to an analysis of total distillate oil deliveries to local customers as estimated in the energy balance sector of this study.

A3.8.2.4 Residual and Heavy Distillate Fuel Oil Sulfur Content

Heavy fuel oil sulfur content varies considerably depending on the sulfur content of the crude oil from which it was refined. The maximum fuel sulfur content permitted for stationary combustion sources in the South Coast Air Basin in 1973 was 0.5% sulfur by weight. From data developed in the detailed inventory of Appendix A2 to this study, it was found that the 1973 average sulfur content of electric utility fuel was 0.43% sulfur by weight. Most industrial residual fuel oil recorded in that survey had a sulfur content of about 0.40%. The sulfur content of residual fuel oil produced from Los Angeles Basin crude oils is much higher than 0.5%. Hence, it is expected that the sulfur content of much of the residual oil exported from the basin will be much higher than that burned locally. The Bureau of Mines (1973b) places typical Western Region Grade 6 residual oil sulfur content at 1.58% by weight in 1973. That value will be adopted as an average for all high sulfur oil uses in 1973. It is worth noting, however, that the reported average sulfur content of Western Region residual oils is not very stable, and that significantly higher sulfur content levels were reported for both 1972

and 1974.

The demand for imported residual oil was probably generated by a need for power plant fuel that would meet local emission control requirements. Therefore, imported residual fuel oil was treated as having a sulfur content like that of power plant fuels for the purposes of calculating the sulfur inflows of Table A3.9.

A3.8.2.5 Petroleum Coke Sulfur Content

Data on the sulfur content of petroleum coke are unavailable from the Bureau of Mines. On the basis of the sulfur flows leaving local refineries in petroleum coke daily (Southern California Air Pollution Control District, 1976a) plus our estimate of the energy content of local coke production, it was estimated that petroleum coke contained about 1.61% sulfur by weight. That estimate is higher than the 1.4% sulfur reported by local coke calciners to Hunter and Helgeson (1976), but lower than we would expect for a production weighted average of petroleum coke made from high sulfur California crude oils. In the absence of comprehensive survey information on coke sulfur content, our estimate should be viewed with caution.

A3.8.2.6 Asphalt, Lubricating Oils and Other Hydrocarbons

Of this group of miscellaneous products, only asphalts and road oils are expected to have a high sulfur content. Imports of asphalt products into the basin are negligible. Although the imports of lubricants and petrochemical feedstocks are higher, their sulfur content is low. Therefore, sulfur inflows into the air basin in these miscellaneous products are thought to be small and will be neglected.

A3.8.3 Digester Gas Sulfur Content

Digester gas is apparently not a uniform product. Sulfur content estimates obtained from various treatment plant operators range from 70 ppm $H_2S$ up to 600 ppm $H_2S$ (Rojas, 1976; Frieling, 1976; Clark, 1976). A sulfur content of 600 ppm $H_2S$ was used as an upper limit to the sulfur contained in digester gas when constructing this sulfur balance. Since only small quantities of this fuel are burned in the basin, an extremely precise estimate of digester gas sulfur content is unnecessary.

A3.8.4 Natural Gas, LPG and NGL Sulfur Content

Based on Environmental Protection Agency (1973) emission factor data, the nationwide sulfur content of natural gas is about 0.3 lbs/mmcf. The sulfur content of natural gas is so low that no attempt was made to further refine EPA's nationwide estimate. As by-products of natural gas production, the sulfur content of LPG and NGL is similarly very low. Lacking any additional data, the sulfur content per $10^{12}$ BTU's estimated for natural gas will be assumed to approximate that for LPG and NGL as well.

A3.8.5 Coal Sulfur Content

Virtually all of the coal entering the South Coast Air Basin is destined for coke production. The only western coal mining districts listed by the Bureau of Mines (1975e) as having production for coke plants sufficient to meet the basin's import needs are in Utah and southern Colorado. The southern Colorado mines produced coking coal with a sulfur content of 0.6% sulfur by weight. The Utah mines coking

coal was 0.8% sulfur by weight. Therefore, an average sulfur content for South Coast Air Basin coal receipts was taken as 0.7% sulfur by weight.

## A3.9 Sulfur Flows in the Energy Transformation Sector

### A3.9.1 Petroleum Refining

The Southern California Air Pollution Control District (1976a) has prepared a sulfur balance on Los Angeles County oil refineries for the year 1973, as shown in Table A3.11. Since these data were obtained directly from the refineries involved, they are assumed to represent sulfur flows far more accurately than could be estimated from regional commerce statistics such as are available from the Bureau of Mines. Therefore the APCD refinery sulfur balance will be used as the basis for characterizing the distribution of sulfur between the large number of products leaving South Coast Air Basin refineries.

Use of the APCD refinery sulfur balance places some constraints on the product categories which may be treated separately as they leave the refineries in our sulfur survey. The APCD study classifies refined products by boiling range rather than by intended use. Jet fuel, utility turbine fuel and kerosene heating oil, for instance, would all be included under the category "light distillates". Therefore, in order to make the APCD survey compatible with our energy balance, the number of separately identified products must be reduced. The sulfur flows contained in the APCD's light distillates and middle distillates categories will be merged and assumed to

TABLE A3.11

1973 Sulfur Balance
Los Angeles County Refineries plus Refinery-Owned
Sulfur Recovery Plants
(Summarized from APCD Format)

| Line number ( ) and process stream | Sulfur (1000 lbs/day) |
|---|---|
| Sulfur in feed | |
| (1) virgin crudes | 3,088.09 |
| (2) reduced crudes | 396.43 |
| (3) purchased gas fuel | 0.22 |
| (4) misc | 216.15 |
| TOTAL SULFUR IN | 3,700.89 |
| Sulfur in Products | |
| (5) fuel gas | 0.07 |
| (6) LPG-LNG | 0.13 |
| (7) gasoline | 81.88 |
| (8) light distillates | 35.09 |
| (9) middle distillates | 100.56 |
| (10) heavy distillates | 177.09 |
| (11) fuel oils | 575.03 |
| (12) crudes | 149.18 |
| (13) coke | 332.11 |
| (14) sulfur | 1,769.24 |
| (15) misc | 216.97 |
| Total sulfur out in products | 3,437.35 |
| Sulfur to Atmosphere | |
| (16) fuel gas | 2.49 |
| (17) fuel oil | 9.19 |
| (18) industrial processes (summation) | 53.77* |
| (19) from sulfur plant | 61.68 |
| Total sulfur to atmosphere | 127.13 |
| Sulfur in Liquid Waste | |
| (20) total sulfur in liquid waste | 134.95 |
| TOTAL SULFUR OUT | 3,699.41 |

* corrected for addition error in APCD table.

represent the combined total of the sulfur contained in jet fuel plus light and middle distillate heating, turbine, and diesel oils. Similarly, the APCD sulfur flows contained in heavy distillate oils will be combined with their fuel oil (residual oil) totals to form a heavy fuel oil category. Petroleum refinery products (other than petroleum coke) which are destined for non-fuel use will be grouped into a miscellaneous products total. Finally, in line with our practice developed in the energy balance, the sulfur contained in topped crude and other unfinished oils output of the refineries will be subtracted from gross refinery input feedstocks in order to show as feedstocks only the net fresh feed to the refinery complex. Refinery fuels burned will be separated from other refinery input feedstock.

In addition to the refinery sulfur balance, the APCD has developed a sulfur balance on the sulfur recovery and sulfuric acid plants associated with local refineries, as shown in Table A3.12. Some of these sulfur recovery operations are owned by oil refineries and their product output is shown as sulfur on both the sulfur plant balance and the refinery balance. In other cases, sulfuric acid produced at refinery-owned acid plants is included within the miscellaneous products category of the refinery balance. However, several refineries do not operate their own sulfur recovery or acid plants. Instead $H_2S$ and acid sludge are sent to separately operated chemical plants for further processing. In some cases, this $H_2S$ is included within the "sulfur" product output of the refinery balance. In other cases, either $H_2S$ or sulfuric acid produced must appear in the miscellaneous

TABLE A3.12

1973 Sulfur Balance
All Sulfur Recovery and Sulfuric Acid Plants
Associated with Los Angeles County Refineries

| Line number ( )* and process stream | Sulfur (1000 lbs/day) |
|---|---|
| Sulfur in feed | |
| (21) hydrogen sulfide burned | 1,980.4 |
| (22) acid sludge burned | 363.4 |
| (23) sulfur burned | 420.8 |
| TOTAL SULFUR IN | 2,764.6 |
| Sulfur in products | |
| (24) elemental sulfur | 1,720.74 |
| (25) sulfuric acid | 959.40 |
| (26) other | 5.80 |
| Total sulfur in products | 2,685.94 |
| Sulfur to atmosphere | |
| (27) total sulfur to atmosphere | 81.46 |
| TOTAL SULFUR OUT | 2,767.4 |

*Continued from Table A3.11.

products category in order for the refinery sulfur balance to actually balance.

In order to place all refinery operations on a common basis, an attempt was made to unbundle the sulfur recovery plants from the refinery sulfur balance. This task is rendered rather difficult by the fact that the APCD sulfur balance data were aggregated to a basin-wide level before public release in order to conceal proprietary information on each sulfur plant's product output. Individual refinery/sulfur plant relationships were obscured to the point where it is difficult to determine where the feedstock materials entering the sulfuric acid production process (Table A3.12) appear on the refinery balance (Table A3.11). Therefore some assumptions were made. It was assumed that refineries produced at least as much $H_2S$ as the sulfur recovery and acid plants burned in 1973. That $H_2S$ quantity received by sulfur recovery and acid plant operations exceeds the total of "sulfur" produced and "sulfur plant emissions" given in the refinery balance of Table A3.11. It was therefore assumed that the remainder of the sulfur as $H_2S$ needed to meet indicated sulfur recovery and acid plant $H_2S$ intake appears as either $H_2S$ or sulfuric acid in the miscellaneous refinery products total of Table A3.11. The sulfur contained in the miscellaneous products category of the refinery balance was reduced accordingly. In place of "sulfur", "sulfur plant emissions", and the acid plant production portion of the miscellaneous products total, a single refinery product called "$H_2S$" was created. This reformatted version of the refinery sulfur

balance is given in Table A3.13, along with appropriate notes showing the correspondence between that table and Tables A3.11 and A3.12. It was further assumed that acid sludge appearing on the sulfur recovery and acid plant balance was not included as a product in the refinery balance. That seems reasonable since the acid sludge appears to be recycled process acid from the refineries and not a direct product of the sulfur contained in the oil being refined. Many of the ambiguities in the relationship between acid plant operation and the refinery sulfur balance could be resolved from APCD files if the production information on individual plants were not confidential.

### A3.9.2 Electric Utility Fuel Combustion

The sulfur content of electric utility heavy fuel oil was determined in Appendix A2 as 0.43% sulfur by weight in 1973. Light fuel oils used by utility internal combustion engines averaged about 0.05% sulfur in that year. Virtually all sulfur entering electric generating stations in fuel is released to the atmosphere in the form of sulfur oxides air pollutant emissions, as indicated in Table A3.14.

## A3.10 Sulfur Flows in the End Use Consumption Sector

Fuels burned in the end use consumption sector of the energy balance release virtually all of their sulfur to the atmosphere in the form of sulfur oxides air pollutant emissions. Emission factors from Table A3.10 were used to convert the energy units of Table A3.6 into the sulfur flow statement shown in Table A3.15. In most cases, the appropriate choice of emission factor is apparent from Tables A3.6 and A3.10. Grade 2 distillate oil sulfur content was used to

TABLE A3.13

Reformatted Sulfur Balance on Los Angeles Refineries - 1973
(Excluding acid plant and sulfur recovery operations)

| | Sulfur (1000 lbs/day) | Notes: |
|---|---|---|
| Refinery Input including all fuels burned | | |
| Net input feedstock | 3,551.49 | Refinery balance lines (1)+(2)+(4)-(12) |
| Refinery fuels consumed | | |
| Natural gas | 0.04 | Calculated from energy balance & % sulfur in fuel |
| Still gas and LPG | 2.45 | Refinery balance line (16) less natural gas above |
| All fuel oils | 9.19 | Refinery balance line (17) |
| TOTAL SULFUR IN | 3,563.17 | |
| Refinery Output including refinery fuel | | |
| Still gas and LPG | 2.65 | Refinery balance lines (5)+(6)+still gas and LPG burned |
| Gasoline | 81.88 | Refinery balance line (7) |
| Jet fuel; light and middle distillate oil | 135.65 | Refinery balance lines (8)+(9) |
| Residual and heavy distillate oil | 761.31 | Refinery balance lines (10)+(11), plus fuel oil burned line (17) |
| Petroleum coke | 332.11 | Refinery balance line (13) |
| Miscellaneous products | 67.49 | Refinery balance lines (14)+(15)+(19) less $H_2S$ to sulfur and acid plants from sulfur plant balance line (21) |
| $H_2S$ to sulfur recovery and acid plants | 1,980.40 | Sulfur recovery plant balance line (21) |
| Sulfur to atmosphere | | |
| Fuel combustion | 11.68 | Refinery balance lines (16)+(17) |
| Industrial processes excluding sulfur recovery and sulfuric acid | 53.77 | Refinery balance lines (18)+(19) |
| Liquid wastes | 134.95 | Refinery balance line (20) |
| TOTAL SULFUR OUT | 3,561.89 | |

TABLE A3.14

Sulfur Emissions from Electricity Generation
Within the South Coast Air Basin - 1973

| Fuel Burned | Thousands of pounds of sulfur per average day |
|---|---|
| Natural Gas | 0.12 |
| Heavy Fuel Oil | 235.22 |
| Light Distillate Oils | 0.18 |
| Digester Gas | 0.07 |
| Subtotal | 235.59 |
| Emissions to the Atmosphere | 235.59 |

# TABLE A3.15

## Sulfur Flows in the Energy Resources Used by Final Consumers in the South Coast Air Basin - 1973

(in 1000's lbs sulfur per day)

| | Natural Gas | LPG | Gasoline | Jet Fuel | Light and Middle Distillate Fuel Oil | Residual and Heavy Distillate Fuel Oil | Petroleum Coke Calcining | Coal | Digester Gas | Sulfur Sufficient to Balance Raw Materials Processing Losses | Solid Wastes | Atmospheric Emissions: Industrial Process | Atmospheric Emissions: Fuel Burning |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| END USE CONSUMPTION SECTOR | | | | | | | | | | | | | |
| Sulfur from Fuel Combustion in Basin | | | | | | | | | | | | | |
| System uses; losses | -0.016 | | | | | | | | | | | | 0.016 |
| Residential/commercial | -0.334 | -0.005 | | | -2.80 | -4.64 | | -0.32 | | | | | 8.10 |
| Industrial (other than refinery) | -0.119 | -0.001 | | | -5.40 | -11.18 | | -91.41 | -0.56 | | 50.05 | | 58.62 |
| Transportation (civilian) | | | | | | | | | | | | | |
| Motor vehicles | | -0.001 | -41.12 | | -13.69 | | | | | | | | 54.81 |
| Aircraft | | | -0.03 | -1.07 | | | | | | | | | 1.10 |
| Railroads | | | | | -5.42 | -0.06 | | | | | | | 5.48 |
| Ships | | | | | -2.85 | -21.58 | | | | | | | 24.43 |
| Military | | | -0.14 | -0.81 | -2.07 | -0.24 | | | | | | | 3.26 |
| Miscellaneous | -0.007 | -0.002 | | | -4.63 | -0.34 | | | | | | | 4.98 |
| Subtotal (from fuels) | -0.48 | -0.01 | -41.29 | -1.88 | -36.86 | -38.04 | | -91.73 | -0.56 | | 50.05 | | 160.80 |
| ADJUSTMENT FOR EFFECT OF RAW MATERIALS PROCESSING INDUSTRIES | -0.01 | -0.01 | | | | | -25.52 | | | -17.69 | | 43.21 | |

Note: '-' indicates sulfur in.
'+' indicates sulfur out.

calculate distillate oil sulfur emissions by residential/commercial and industrial customers. Military and miscellaneous distillate oil demands were assumed to be principally for vehicle diesel engine fuel. Heavy bunker oil combustion by civilian and military ships was calculated as if high sulfur fuel oil were used. All remaining heavy oil uses within the basin were inventoried at 0.40% sulfur in the fuel.

Use of coking coal in the largest steel mill in the Los Angeles area must be treated as a special case in our sulfur balance. Sulfur is released to the atmosphere from both the coal being fed to the mill's coke ovens, and from the sintering of sulfur-bearing ores. Furthermore, some of the fuel sulfur reaching the mill's furnaces is captured by the use of slag mixtures and eventually becomes part of a solid waste product. In order to separate iron ore sulfur released from fuel sulfur released, an attempt was made to construct a sulfur mass balance on the steel mill's sinter plant. That effort failed when the balance showed much more sulfur lost from the process than Hunter and Helgeson's (1976) stack tests would indicate is going to the atmosphere. Without the ability to retest the plant or to acquire further process information, the sulfur oxides emissions from Appendix A2 to this report will be accepted as representing sulfur released to the atmosphere from the entire steel mill. Those emissions will be subtracted from estimated fuel sulfur input in coal, and the remaining fuel sulfur will be assumed to be tied-up in slag solid wastes. The atmospheric emissions presented in

this manner will be within reason, but the sulfur contained in iron ore will not show explicitly on the basin's sulfur balance and the quantity of sulfur captured in solid wastes will be too low.

Construction of a sulfur balance on the raw materials processing industries in Los Angeles could become very complicated. A number of industrial processes exist which release sulfur from mineral products and scrap being processed rather than from the fuel being burned. The total quantity of mineral products, scrap batteries, fluxes, coloring agents and the like charged to these processes in 1973 is unknown to us because production rate information of this type is confidential and will not be released by the local APCD. Instead, our sulfur balance will include adjustments for the effect of the reported atmospheric emissions from these industrial processes. These adjustments are shown at the bottom of Table A3.15. Sulfur in energy products which are consumed as a feedstock by industrial processes is shown as a negative entry in that table. Industrial process emissions to the atmosphere are shown as a positive flow. These emissions estimates are taken from Tables A2.15a and A2.15b. They represent the sum of emissions from coke calcining kilns, glass furnaces, secondary metals furnaces, other minerals industries, incinerators, oil field production operations, chemical plants other than sulfur recovery and sulfuric acid plants, and miscellaneous industrial processes.

### A3.11 Sulfur Exported from the South Coast Air Basin

Sulfur contained in fuels exported from the South Coast Air Basin in 1973 is summarized in Table A3.16.

#### A3.11.1 Natural Gas Sulfur Exported

Sulfur leaving the basin in natural gas was estimated from the energy exports given in Table A3.7. The sulfur content assumed for that natural gas is given in Table A3.10.

#### A3.11.2 Net Crude Oil Sulfur Exported

The sulfur content of net crude oil exports from local oil fields was estimated from data in Appendix A1, Tables A1.6 and A1.10. Sulfur exported in crude oil was taken as sulfur produced in oil from Los Angeles Basin and Ventura area fields less the sulfur content of local oil production kept for processing in local refineries (i.e. production less refinery receipts).

#### A3.11.3 Sulfur Contained in Refined Petroleum Products Exported from Local Harbors

The energy content of refined product exports from local harbors is shown in Table A3.7. The sulfur content of these products is given in Table A3.10. Many of these exported product streams contain fuels of varying sulfur content. As was the case with our imported refined products, some assumptions must be made about the product mix represented by "jet fuel", distillate oil and residual oil. Jet fuel was taken to be 87% commercial type and 13% military type, as was assumed in our discussion of jet fuel imports. Distillate oil sulfur content was estimated from a blend of distillate oil types,

TABLE A3.16

South Coast Air Basin Sulfur Exports-1973

| | 1000 lbs Sulfur per Day |
|---|---|
| Natural Gas | |
| Out-of-basin sales to Pacific Lighting customers | 0.07 |
| Sales to San Diego Gas & Electric | 0.07 |
| Exchange with out-of-basin utility | 0.004 |
| Subtotal | 0.14 |
| Crude Oil - Net | |
| Los Angeles and Ventura oil shipped to sea less estimated return flows of that oil at other South Coast Air Basin ports | 121.8 |
| Petroleum Product Exports | |
| Harbor exports | |
| Gasoline | 3.03 |
| Jet fuel | 1.23 |
| Distillate oil and kerosene | 31.60 |
| Residual oil | 302.57 |
| Petroleum coke | 320.44 |
| Lubricants and greases | (small) |
| Asphalt and asphalt materials | ~40.0 |
| LPG | ~ 0 |
| Other | (small) |
| Subtotal | 698.87 |
| Overland transport | |
| Arizona and southern Nevada | |
| Gasoline | 5.73 |
| Jet fuel | 1.54 |
| Light and middle distillate oil | 18.64 |
| Residual oil | 16.99 |
| Inland to southern California | |
| Gasoline | 6.59 |
| Subtotal | 49.49 |
| Exported in transport mode fuel tanks | |
| Transportation (civilian) | |
| Aviation gasoline | 0.24 |
| Jet fuel | 6.17 |
| Distillate bunker fuel | 1.22 |
| Residual bunker fuel | 203.12 |
| Military | |
| Aviation gasoline | 0.00 |
| Jet fuel | 1.49 |
| Residual bunker fuel | 3.12 |
| Subtotal | 215.36 |
| Raw Materials | |
| Elemental sulfur (harbor export) | 1.67 |
| TOTAL INVENTORIED EXPORTS | 1,087.33 |

in the same proportions as assumed for imports in Section A3.8.2.3 of this survey.

Residual fuel oils shipped from local harbors principally consist of high sulfur oils destined for other ports where burning higher sulfur oil is within legal limits. However, a substantial quantity of low sulfur residual oil is apparently also shipped in coastal commerce from harbors in the Los Angeles area to fuel power plants located elsewhere on the California coast. Examination of our fuel oil import records at Huntington Beach, Port Hueneme, Carpenteria and Ventura showed residual oil imports from domestic sources equal to about 25% of the gross South Coast Air Basin residual oil shipments to sea. While all of that oil received may not have come from South Coast Air Basin refineries, there is similarly no lack of other non-South Coast Air Basin power plants along the California coast to which low sulfur fuel might be shipped by sea. Therefore it seemed reasonable to estimate that about 25% of the residual oil exported to sea from local harbors was of the low sulfur power plant fuel oil variety. All remaining heavy oil exports were assumed to represent disposal of high sulfur fuel oil refined from crude oil which will not meet local sulfur content limits.

A significant quantity of sulfur leaves the air basin by ship in petroleum coke and asphalt. The sulfur content of petroleum coke was estimated in Table A3.10. The sulfur content of asphalt is not known to us but is probably not too much different than that of petroleum coke.

If that were the case, about 40 thousand pounds of sulfur would leave the basin daily in exported asphalt. However, since actual data on the sulfur content of asphalt is not available, an export estimate for it will not be entered into the sulfur balance. Instead, all miscellaneous hydrocarbons (except petroleum coke) which are not ultimately used for fuel will be considered to have an unknown sink from which their sulfur content is not released to the atmosphere.

### A3.11.4 Sulfur Contained in Petroleum Products Exported by Overland Transportation Modes

The energy content of fuels shipped out of the basin by overland transport modes is shown in Table A3.7. Jet fuel and distillate oils exported were assumed to be mixtures of the fuel types used in the South Coast Air Basin in the proportions indicated for imports in sections A3.8.2.2 and A3.8.2.3 of this survey. Based on conversations with personnel at the air pollution control agencies for the State of Arizona (Rowe, 1977) and Clark County (Las Vegas), Nevada (Neeler, 1977), it was found that power plants in those areas burned low sulfur fuel oil. Therefore, residual oil exports to Arizona and Southern Nevada were inventoried at the sulfur content given in Table A3.10 for South Coast Air Basin low sulfur power plant fuel.

### A3.11.5 Sulfur Exported in the Fuel Tanks of Long Range Transportation Vehicles

The energy content of fuels leaving the South Coast Air Basin in aircraft and ship fuel tanks is detailed in Table A3.7. Sulfur flows associated with those energy exports were inventoried using factors presented in Table A3.10. Distillate bunker fuels were taken

to be Type SM diesel fuel. Residual bunker fuel was assumed to be of the high sulfur fuel oil variety.

A3.11.6 Raw Material Exports

Harbor records given in Waterborne Commerce of the United States (Corps of Engineers, 1973) show a small amount of elemental sulfur exported from South Coast Air Basin harbors. That sulfur export has been entered in Table A3.16. Other quantities of sulfur or sulfuric acid may leave the air basin by overland transportation modes, but data on those shipments are unknown to us.

A3.12 The Sulfur Balance

Table A3.17 summarizes the sulfur balance on the South Coast Air Basin for the year 1973. An estimated total of 4.2 million pounds of sulfur per day was tracked through the basin's economy. Over ninety percent of that sulfur input originally accompanied crude oil.

The estimated fate of that sulfur supply is also given in Table A3.17:

- Nearly half of the sulfur was captured at sulfur recovery and sulfuric acid plants;
- Approximately one quarter of the sulfur was exported from the basin in finished petroleum products;
- 4.4% of the sulfur supply found its way into solid or liquid wastes;
- At least 14% of the sulfur was emitted to the atmosphere in the form of 586.51 tons per day of sulfur oxides air pollutants (stated as $SO_2$); and

# TABLE A3.17

## South Coast Air Basin Sulfur Balance - 1973
## (1000's lbs sulfur per day)

| | Natural Gas | Crude Oil; Unfinished Oils & Other Refinery Feedstocks | LPG and Still Gas for Fuel | Gasoline | Light and Middle Distillates & Jet Fuel | Residual and Heavy Distillate Fuel Oil | Petroleum Coke | Misc. Petroleum Products | Coal | Digester Gas | Hydrogen Sulfide | Sulfur | Acid Sludge | Sulfuric Acid | Misc. Indus. Raw Materials Sufficient to Balance Process Losses | Solid or Liquid Waste | Atmospheric Emissions: Industrial Process | Atmospheric Emissions: Fuel Burning | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SOURCES** | | | | | | | | | | | | | | | | | | | |
| Resource base: imports plus local crude oil and natural gas production | 0.81 | 3942.5 | 0.01 | 4.40 | 29.76 | 77.70 | 16.11 | small | 91.73 | 0.63 | | 0.06 | | | 17.69 | | | | |
| Adjustments: change in gas storage | -0.02 | | | | | | | | | | | | | | | | | | |
| Subtotal | 0.79 | 3942.5 | 0.01 | 4.40 | 29.76 | 77.70 | 16.11 | | 91.73 | 0.63 | | 0.06 | | | 17.69 | | | | 4181.38 |
| **TRANSFORMATION SECTOR** | | | | | | | | | | | | | | | | | | | |
| Refinery | | | | | | | | | | | | | | | | | | | |
| Feedstock sulfur | | -3551.5 | | | | | | | | | | | | | | | | | |
| Fuel sulfur | -0.04 | | -2.45 | | | -9.19 | | | | | | | | | | | | | |
| Products and wastes | | | 2.65 | 81.88 | 135.65 | 761.31 | 332.11 | 67.49 | | | 1980.4 | | 363.4 | -363.4 | | 134.95 | 53.77 | 11.68 | |
| Sulfur Recovery and Sulfuric Acid | | | | | | | | | | | | | | | | | | | |
| Feedstock sulfur | | | | | | | | | | | -1980.4 | -420.8 | -363.4 | | | | | | |
| Products and wastes | | | | | | | | 5.80 | | | | 1720.7 | | 959.4 | | | 81.46 | | |
| Electric Utilities | | | | | | | | | | | | | | | | | | | |
| Fuel sulfur | -0.12 | | | | -0.18 | -235.22 | | | | -0.07 | | | | | | | | 235.59 | |
| Subtotal | -0.16 | -3551.5 | 0.20 | 81.88 | 135.47 | 516.90 | 332.11 | 73.29 | | -0.07 | 0 | 1299.90 | 0 | 596.0 | | 134.95 | 135.23 | 247.27 | 1.47 |
| **END USE CONSUMPTION SECTOR** | | | | | | | | | | | | | | | | | | | |
| (Fuel Combustion in Basin) | | | | | | | | | | | | | | | | | | | |
| System uses; losses | -0.02 | | | | | | | | | | | | | | | | | 0.02 | |
| Residential/commercial | -0.33 | | -0.005 | | -2.80 | -4.64 | | | -0.32 | | | | | | | | | 8.10 | |
| Industrial (other than refinery) | -0.12 | | -0.001 | | -5.40 | -11.18 | | | -91.41 | -0.56 | | | | | | 50.05 | | 58.62[a] | |
| Transportation (civilian) | | | -0.001 | -41.15 | -23.03 | -21.64 | | | | | | | | | | | | 85.82 | |
| Military | | | | -0.14 | -2.88 | -0.24 | | | | | | | | | | | | 3.26 | |
| Miscellaneous | -0.01 | | -0.002 | | -4.63 | -0.34 | | | | | | | | | | | | 4.98 | |
| Subtotal | -0.48 | | -0.01 | -41.29 | -38.74 | -38.04 | | | -91.73 | -0.56 | | | | | | 50.05 | | 160.80 | 0.00 |
| **ADJUSTMENT FOR EFFECT OF RAW MATERIALS PROCESSING INDUSTRIES** | -0.01 | | -0.01 | | | | -25.52 | | | | | | | | -17.69 | | 43.21[b] | | -0.02 |
| **EXPORTS** | | | | | | | | | | | | | | | | | | | |
| As a commodity (by ship) | -0.07 | -121.8 | ~0 | -3.03 | -32.83 | -302.57 | -320.44 | | | | | -1.67 | | | | | | | |
| As a commodity (overland) | -0.07 | | | -12.32 | -20.18 | -16.99 | | | | | | unknown | | | | | | | |
| In transport mode fuel tanks | | | | -0.24 | -8.88 | -206.24 | | | | | | | | | | | | | |
| Subtotal | -0.14 | -121.8 | ~0 | -15.59 | -61.89 | -525.80 | -320.44 | | | | | -1.67 | | | | | | | -1047.33 |
| **SINK FOR MISC. NON-FUEL RESOURCES WHOSE ULTIMATE CUSTOMER WILL NOT BE SOUGHT** | | | | | | | | -73.29 | | | | -1298.29 | | -596.0 | | | | | -1967.58 |
| **SUMMARY** | | | | | | | | | | | | | | | | | | | |
| Total sources (+ flows) | 0.81 | 3942.5 | 2.66 | 86.28 | 165.41 | 839.01 | 348.22 | 73.29 | 91.73 | 0.63 | 1980.4 | 1720.76 | 363.4 | 959.4 | 17.69 | 185.00 | 586.51 | | |
| Total sinks (- flows) | -0.81 | -3673.3 | -2.47 | -56.88 | -100.81 | -808.25 | -345.96 | -73.29 | -91.73 | -0.63 | -1980.4 | -1720.76 | -363.4 | -959.4 | -17.69 | | | | |
| Absolute difference | 0 | 269.2 | 0.19 | 29.40 | 64.60 | 30.76 | 2.26 | | | | | | 0 | | | | | | 393.41 |
| Difference as % of sources | 0 | +6.8% | +7.1% | 34.1% | 39.1% | 3.7% | 0.65% | | | | | | | | | | | | |
| Difference as % of total sulfur input of 4181.38 thousand lbs/day | 0 | 6.4% | ~0% | 0.70% | 1.54% | 0.74% | 0.05% | | | | | | | | | | 14.0% | | |

Notes: (a) This fuel burning total includes 41.36 thousand pounds of sulfur per day from combined fuel burning and industrial processes activities at Kaiser Steel.

(b) These industrial process emissions include

| | |
|---|---|
| misc. chemical industries | 0.09 |
| oil field production | 4.50 |
| petroleum coke kilns | 25.52 |
| glass furnaces | 2.33 |
| metals industries | 8.88 |
| minerals industries | 1.90 |
| other industrial processes | 0.02 |
| incinerators | 0.07 |

- The fate of 9.4% of the sulfur supply remains undetermined.

In contrast to the energy balance, the sulfur balance at first glance does not appear to balance closely. The explanation for that problem, however, seems fairly straightforward.

The largest discrepancy between sulfur supply and consumption lies in the crude oil column of Table A3.17. While supply exceeds known crude oil sulfur consumption by only 6.8%, that 6.8% difference is applied to two very large sulfur flows. One reason for this gap between estimated supply and demand lies in the fact that the APCD survey used to estimate sulfur intake by refineries did not include at least two small refineries which accounted for about 1% of the basin's daily crude oil demand in 1973. Refinery sulfur intake and output should be about 1% higher than shown if more complete data were available on those small refineries. The remaining five to six percent surplus of crude oil sulfur supplied probably represents an overestimate of either crude oil intake or crude oil sulfur content as part of the study conducted in Appendix A1 to this report. Considering the difficulty in estimating the origin of some of the crude oils received in the basin, that small percentage disagreement will be considered nearly unavoidable. Provided that the APCD refinery sulfur balance is correct, any overestimate of crude oil sulfur supply from Appendix A1 will not affect the rest of the sulfur flows shown in Table A3.17, nor will it inflate any atmospheric emissions estimates. With the crude oil sulfur discrepancy set aside, the remainder of the sulfur balance balances to within about 3%.

Turning to individual product streams, we note that the sulfur balances on the heavy petroleum products appear reasonable. Petroleum coke sulfur balances to within less than a 1% surplus, and heavy fuel oil balances to within 3.7%. Those two products account for about 28% of the total sulfur in the system.

Heavy fuel oil combustion in the basin is the largest single source of sulfur oxides air pollutant emissions, accounting for just under half of total emissions to the atmosphere. It is therefore reassuring to obtain a fairly close sulfur balance on supply and use for this product.

Petroleum coke is produced almost exclusively for export from the basin. Significant emissions to the atmosphere come from the petroleum coke calcining industry (25.22 tons/day as $SO_2$; see adjustment for raw materials processing or Appendix A2). In that process, coke is carbonized in preparation for manufacturing electrodes.

At the lightest product end of the sulfur balance, results also seem acceptable. Natural gas and refinery gases (LPG and still gas) contain practically no sulfur even though they accounted for a third of the basin's total energy supply in 1973.

In spite of the fact that the energy balance on gasoline closed almost exactly, the fate of 34% of the sulfur distributed in gasoline in 1973 remains undetermined. The apparent explanation is that the

Bureau of Mines gasoline grab samples for that year were not representative of a production weighted average of local refinery products. Consider the following evidence to that effect.

Table A3.18 shows refinery sulfur output in gasoline for the years 1973 and 1974 as reported by refineries to the local air pollution control district. An estimate of the weight percent sulfur in gasoline implied by those refinery reports has been made for comparison with Bureau of Mines data. As can be seen, the refinery reports to the APCD closely follow the Bureau of Mines sulfur samples in 1974. For 1973, however, either the Bureau of Mines samples are far too low, or the APCD sulfur balance is too high.

Since local refineries would be unlikely to overstate the total tonnage of sulfur distributed in gasoline by 47%, one tends to suspect the Bureau of Mines data. The Bureau of Mines appears to take grab samples of gasoline from a large number of refiners. These samples are first averaged for each refiner and then each refiner is weighted equally when computing the Southern California average gasoline sulfur content. However two of the eighteen refineries in the South Coast Air Basin accounted for about 40% of local refinery capacity in 1973. Unless the sulfur content of gasoline from the basin's large refineries is weighted by their market share, the Bureau of Mines would not be able to compute a gasoline pool average sulfur content with any accuracy unless all gasoline samples were of about the same sulfur content. Bureau of Mines test results show wide variance in gasoline sulfur content between refineries. One therefore suspects

TABLE A3.18

Comparison of Bureau of Mines Gasoline Sulfur Content Data to the Sulfur Content of Gasoline Estimated from Refinery Reports to the Southern California APCD

| Calendar Year | Sulfur distributed in gasoline (1000's lbs/day)[a] | Sulfur distributed as weight percent of gasoline production (approximate)[b] | Average Weight Percent Sulfur in gasoline as implied by Bureau of Mines[c] |
|---|---|---|---|
| 1973 | 81.88 | 0.070% | 0.047% |
| 1974 | 55.89 | 0.048% | 0.049% |

(a) Based on refinery reports to the Southern California Air Pollution Control District (1976a).

(b) Based on an approximate gasoline production rate for local refineries of 450 thousand barrels per day in both years (estimated from Table A3.3).

(c) See Table A3.10.

that their average sulfur content values could be quite a bit in error if used to represent a gasoline pool average.

Unlike the discrepancy in the crude oil sulfur balance, the gasoline sulfur surplus probably represents a real uncertainty in the basin's atmospheric emissions estimates for 1973. Most gasoline produced in local refineries is actually burned in the basin. If the 1973 gasoline sulfur content were 47% higher than reported by the Bureau of Mines, then atmospheric emissions from gasoline combustion would have been close to 60 tons per day (as $SO_2$) instead of 41 tons per day as calculated from Table A3.17.

A similar problem may have occurred with estimation of light and middle distillate fuel oil sulfur content in 1973. The average sulfur content of distillate oil products shown in Table A3.10 was given by the Bureau of Mines for the entire Western Region of the United States. Since several Southern California refineries handled very high sulfur crude oil, it would not be too suprising if Southern California distillate oil sulfur content were above the Western Region average. However, given the large variety of distillate oil products and the fact that our energy balance on these oils did not close exactly, it is not possible to pinpoint the nature of the imbalance in the distillate oil sulfur pool.

One of the most striking features of the sulfur balance is the relatively high degree of desulfurization of petroleum products that was already occurring at Los Angeles area refineries in 1973. Roughly half of the sulfur entering those refineries was captured as elemental

sulfur or sulfuric acid, rather than leaving the refinery in products or waste discharges.

## References for Appendix A3

American Petroleum Institute (1972), Annual Statistical Review, U. S. Petroleum Industry Statistics, 1956-1971, Washington D. C., May 1972.

Bureau of the Census (1973a), Census of Population: 1970, Vol. 1, Characteristics of the Population, Part 6, California-Section 1, U. S. Department of Commerce.

Bureau of the Census (1973b), Census of Population: 1970, Subject Reports, Final Report PC(2) - 6D, Journey to Work, U. S. Department of Commerce.

Bureau of the Census (1974), U. S. Foreign Trade, Bunker Fuels, Calendar Year 1973, U. S. Department of Commerce, Social and Economic Statistics Administration, Publication FT-810-73-13.

Bureau of Mines (1973a through 1975a), Aviation Turbine Fuels, 1972 (73, 74), U. S. Department of the Interior, Mineral Industry Surveys, Petroleum Products Survey No. 79, 84, 89.

Bureau of Mines (1972b through 1974b), Burner Fuel Oils, 1972 (73, 74), U. S. Department of the Interior, Mineral Industry Surveys, Petroleum Product Survey No. 76, 81, 86.

Bureau of Mines (1975c), "Crude Petroleum, Petroleum Products, and Natural Gas Liquids: 1973", Petroleum Statement, Annual, U.S. Department of the Interior, Mineral Industry Surveys.

Bureau of Mines (1972d through 1974d), Diesel Fuel Oils, 1972, (73, 74), U. S. Department of the Interior, Mineral Industry Surveys, Petroleum Product Survey No. 77, 82, 87.

Bureau of Mines (1975e), Minerals Yearbook, Volume I, Metals, Minerals, and Fuels, 1973, Washington D.C.; Government Printing Office. U. S. Department of the Interior.

Bureau of Mines (1972f through 1975f) Motor Gasolines, Winter 1971-1972 (also Summer 1972, Winter 1972-1973, Summer 1973, Winter 1973-1974, and Summer 1974), U. S. Department of the Interior, Mineral Industry Surveys, Petroleum Products Surveys No. 75,78,80,83,85,88. For continuation of series, see Shelton (1975).

Bureau of Mines (1974g), "Natural Gas Production and Consumption: 1973", Natural Gas, Annual, U. S. Department of the Interior, Mineral Industry Surveys.

Bureau of Mines (1974h), "Sales of Fuel Oil and Kerosene in 1973", Fuel Oil Sales, Annual, U. S. Department of the Interior, Mineral Industry Surveys.

Bureau of Mines (1974i), "Sales of Liquified Petroleum Gases and Ethane in 1973", Liquified Petroleum Gas, Annual, U.S. Department of the Interior, Mineral Industry Surveys.

California, State of (1974), California Statistical Abstract, 1974.

California Energy Planning Council (1974), California Energy Outlook, 1974-1975, an advisory council to the governor of the state of California, Harold Bertholf, Executive Secretary of the council.

California Public Utilities Commission (1975), Decision No. 85189, San Francisco, California, December 2, 1975.

Carey, R. T., ed. (1974) California County Fact Book 1974, Sacramento, California, County Supervisors Association of California and California County Government Education Foundation.

Clark, W. (1976), Orange County Sanitation District, personal communcation, June 25, 1976.

Compton Airport Personnel (1976), personal communication.

Corps of Engineers (1973), Waterborne Commerce of the United States, Calendar Year 1973, Part 4, Waterways and Harbors, Pacific Coast, Alaska and Hawaii, U. S. Department of the Army.

Department of Airports (1976), City of Los Angeles, personal communication.

Department of Water and Power (1972a through 1975a), 1971-72, Seventy First Annual Report, Water and Power (also 1972-73, Seventy Second Annual Report and 1974-75, Seventy-Fourth Annual Report), City of Los Angeles, Board of Water and Power Commissioners.

Department of Water and Power (1975b), Statistical Reports for the Fiscal Years 1966-1975, City of Los Angeles.

Environmental Protection Agency (1973), Compilation of Air Pollutant Emission Factors, Second Edition, Research Triangle Park, North Carolina, U. S. Environmental Protection Agency document No. AP-42.

Environmental Protection Agency (1972), Guide for Compiling a Comprehensive Emission Inventory, Research Triangle Park, North Carolina, U. S. Environmental Protection Agency document No. APTD-1135.

Ethyl Corporation (1974), Yearly Report of Gasoline Sales by State.

Federal Aviation Administration (1973a, 1974a), FAA Air Traffic Activity, Fiscal Year 1973 (74), U. S. Department of Transportation.

Federal Aviation Administration (1976), Lawndale, California, personal communication, August 23, 1976.

Federal Aviation Administration (1974b), Military Air Traffic Activity Report, Calendar Year 1974, U. S. Department of Transportation.

Federal Power Commission (1972c through 1975c), Electric Power Statistics, January 1972 through June 1975, monthly.

Federal Power Commission (1972a through 1974a), Statistics of Privately Owned Electrical Utilities in the United States: 1972 (73, 74).

Federal Power Commission (1972b through 1974b) Statistics of Publicly Owned Electrical Utilities in the United States: 1972(73, 74).

Federal Railway Administration (1976), U. S. Department of Transportation, personal communication, August, 1976.

Frieling, J. (1976), Los Angeles County Sanitation District, $H_2S$ and BTU content of digester gas, personal communication, June 24, 1976.

Hunter, S. C. and N. L. Helgeson (1976), Control of Oxides of Sulfur from Stationary Sources in the South Coast Air Basin of California, Tustin, California, KVB Incorporated, Document No. KVB 5802-432, prepared under California Air Resources Board Contract Number ARB 4-421.

List, E. J. (1971), Energy Use in California: Implications for the Environment, Pasadena, California, California Institute of Technology, Enviornmental Quality Laboratory Report No. 3.

Los Angeles Air Pollution Control District (1971), Study of Jet Aircraft Emissions and Air Quality in the Vicinity of the Los Angeles International Airport.

McCaslin, J. D., ed (1974) International Petroleum Encyclopedia, 1974 edition, Tulsa, Oklahoma, The Petroleum Publishing Co.

Mutch, James J. (1973), Transportation Energy Use in the United States: A Statistical History, 1955-1971, Santa Monica, California, The Rand Corporation, Document No. R-1391-NSF.

National Oceanic and Atmospheric Administration (undated), U. S. West Coast-California-San Diego to Santa Rosa Island (map), U. S. Department of Commerce, National Ocean Survey.

Neeler, M. (1977) District Health Department of Clark County, Nevada, peronal communication, July 11, 1977.

Nelson, T. (1976), Department of Water and Power, City of Los Angeles, Coal-fired electrical generation at DWP plants for fiscal years 1971-72; 1972-73, personal communication, July 19, 1976.

1975 California Gas Report, a report prepared pursuant to California Public Utilities Commission Decision Number 62260; authorship and publisher are unknown, but copies are obtainable from the Southern California Gas Company.

Ontario Airport Personnel (1976), personal communication.

Orange County Airport Personnel (1976), personal communication.

Pasadena, City of, (1974, 1975), Annual Statistical Report, Pasadena Water and Power Department, July 1, 1973 to June 30, 1974 (also July 1, 1974 to June 30, 1975).

Rand McNally (1973), World Atlas, Chicago, Rand McNally.

Rhea, W. (1976), U. S. Environmental Protection Agency, Region IX, air pollutant emission reports for March and Norton Air Force Bases, personal communication, August 4, 1976.

Rojas, R. (1976), City of Los Angeles, Hyperion Treatment Plant, personal communication, June 17, 1976.

Rowe, L. (1977), Arizona Department of Health Services, Bureau of Air Quality, personal communication, July 11, 1977.

San Fernando Airport Personnel (1976), personal communication.

Shelton, E. M., (1975), Motor Gasolines, Winter 1974-75, U. S. Energy Research and Development Administration, publication BERC/PSS-75/1.

"Ship Movements" (1973 through 1976), Los Angeles Times, records of local ship traffic in harbors, numerous dates.

Southern California Air Pollution Control District (1976a), personal communication. The district furnished censored versions of the following internal documents:

(1.) "Sulfur Balance - Los Angeles County Refineries - 1973".
(2.) "Sulfur Balance - Los Angeles County Refineries - 1974".
(3.) "Sulfur Recovery and Sulfuric Acid Plant Operations - Los Angeles County - 1973".
(4.) "Sulfur Recovery and Sulfuric Acid Plant Operations - Los Angeles County - 1974".

Southern California Edison (1974), Annual Report, 1974, Rosemead, California.

Southern California Edison (1972a, 1973a), Financial and Statistical Report, 1972 (73), Rosemead, California.

Southern California Edison (1972b), System Forecasts, 1972-1995, Rosemead, California.

Stanford Research Institute (1973), Meeting California's Energy Requirements, 1975-2000, Menlo Park, California, SRI Project ECC-2355.

Whiteman Airport Personnel (1976), personal communication.

Wood, W. (1977), California Air Resources Board, personal communication, February 2, 1977; provided sales by county and by air basin to firm, interruptible and steam electric customers of the Southern California Gas Co. and the Long Beach Gas Department for 1972, 1973, 1974.

Zwiacher, W. (1975-1976), Southern California Air Pollution Control District, personal communications, numerous dates.

# APPENDIX A4

# PLUME RISE CALCULATIONS

## A4.1 Introduction

In order to characterize the local concentration effects of pollutant emissions from any source, it is necessary to estimate the source's effective stack height. Source effective stack height is the elevation above ground level at which a buoyant plume ceases to rise further into the atmosphere and instead equilibrates with its surroundings. Effective stack height can be thought of as having two component parts: an increment due to the physical stack height which is built into the source, and an increment due to plume rise above the physical stack.

Plume rise in a stratified atmosphere is a complex phenomenon, depending on the physical characteristics of the effluent gases and ambient meteorological conditions. The purpose of this appendix is to present a compilation of relevant stack characterisitics for major $SO_x$ sources in the South Coast Air Basin and to estimate plume rise from a representative set of sources at one set of reference atmospheric conditions. The results of these calculations will be used to establish typical physical stack heights and plume rise behavior for each source class in the emission inventory of Appendix A2 to this study. Then a method will be suggested for dynamically allocating effective stack height as a function of source class and wind speed within a simple emissions/air quality model. It is unrealistic to think that data are

available sufficient to calculate plume rise accurately for all sources under all meteorological conditions. But an approach is developed which at least will distinguish sources with tall effective stacks from those emitting near ground level.

## A4.2 Data Sources

The following stack parameters are required in order to calculate the plume rise from any source using Briggs' (1971) method: the physical stack height, the stack diameter, and the temperature and velocity of the exhaust gases. Several data sources were employed to obtain these parameters for the most significant sulfur oxides sources in the South Coast Air Basin.

The Federal Power Commission (Thomas, 1976) supplied the required stack parameters for the electrical power plants in the basin. These data are reported by the utilities on FPC Form 67 for 50%, 75%, and 100% of full power plant load. In a few cases the stack gas exit velocity was simply estimated rather than measured by the utility. Occasionally it was necessary to calculate the exit velocity from the exhaust gas volumetric flow rate when only the latter was reported.

Stack data on many industrial plants came from measurements made by Hunter and Helgeson (1976) as part of a sulfur oxides source test program conducted for the South Coast Air Basin. Those source tests covered a number of the larger industrial facilities in the basin. Hunter (1975) provided stack data for various refinery fluid catalytic cracking (FCC) units, sulfur recovery plants, sulfuric acid plants,

coke calcining kilns, glass furnaces, and various metallurgical operations. In some cases, particularly where sources were baghouse-controlled, measurements of exit velocity and effective stack diameter were unavailable, but at least the physical stack height is known.

For several additional sulfur oxides sources, stack data were obtained by personal communication with plant personnel.

## A4.3 Calculation Methods

Plume rise is a function of the flux of buoyant force carried by the stack gases. For a buoyant plume of about the same specific heat capacity and molecular weight as air, this flux, divided by $\pi$ and the mean atmospheric density, is given by

$$F = g \frac{\Delta T}{T_s} v_s r^2 \qquad \text{(A4.1)}$$

where

$g$ = gravitational constant

$\Delta T_s$ = temperature difference, $T_{stack} - T_{ambient}$

$T_s$ = the absolute temperature of the stack gases

$v_s$ = stack exit velocity

$r$ = stack radius

F has dimensions of $(\text{length})^4/(\text{time})^3$ and is related to $Q_H$, the heat flux of the plume. For an emission source located near sea level, the conversion formula is:

$$Q_H = F/(4.3 \times 10^{-3}) \qquad \text{(A4.2)}$$

with $Q_H$ in cal/sec and F in $ft^4/sec^3$.

Plume rise ($\Delta H$) was calculated according to the semi-empirical formulas proposed by Briggs (1971) for the final height of rise through a neutral or unstable atmosphere, using:

$$\Delta h = 1.6 \frac{F^{1/3}}{U} (10\ H_s)^{2/3} \qquad \text{for } Q_H \geq 47.8 \times 10^5 \text{ cal/sec} \qquad \text{(A4.3)}$$

$$\Delta h = 1.6 \frac{F^{1/3}}{U} (1.56\ F^{2/5} H_s^{3/5})^{2/3} \qquad \text{for } Q_H < 47.8 \times 10^5 \text{ cal/sec} \qquad \text{(A4.4)}$$

where $H_s$ is the physical stack height and U is the ambient wind speed.

Example calculations shown in Table A4.1 give plume rise, $\Delta H$, for each source for which stack data were obtained. These calculations were made for one set of typical atmospheric conditions, and provide a basis for visualizing relative differences in source plume buoyancy. Results shown in Table A4.1 assume a wind speed of 6.2 mph (2.76 m/sec) and an ambient temperature of 64.4°F (18°C), which are average values for downtown Los Angeles (National Oceanic and Atmospheric Administration, 1974). In order to compute source effective stack height above ground level, plume rise, $\Delta H$ is added to source physical stack height, $H_s$.

TABLE A4.1

Stack Data Buoyancy Flux (F), Heat Flux, ($Q_H$), and Plume Rise (ΔH) for South Coast Air Basin Sulfur Oxides Sources
(calculated for neutral stability, ambient temperature = 64.4°F, wind speed = 6.2 mph)

| Generating Station | Unit Number | Plant Load | Physical Stack Height $H_s$ (ft) | Stack Volumetric Flow Rate (SCFM) | Stack Exhaust Temperature $T_s$ (°F) | Stack Diameter (ft) | Exhaust Gas Velocity $V_s$ (FPS) | Briggs F ($ft^4/sec^3$) | Heat Flux $Q_H$ ($10^5$ cal/sec) | Plume Rise ΔH (ft) | Data Source |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fuel Combustion Sources** | | | | | | | | | | | |
| **Electric Utilities** | | | | | | | | | | | |
| El Segundo | #1&2 | full | 200 | 450,000 | 290 | 12 | 66.3 | 22974 | 53.4 | 794 | FPC |
| | | 75% | | 337,500 | 280 | | 49.7 | 16681 | 38.8 | 673 | FPC |
| | | half | | 225,000 | 270 | | 33.1 | 10739 | 25.0 | 517 | FPC |
| | #3&4 | full | 200 | 854,000 | 235 | 14 | 92.4 | 35564 | 82.7 | 919 | FPC |
| | | 75% | | 640,000 | 205 | | 69.3 | 22974 | 53.4 | 794 | FPC |
| | | half | | 427,000 | 193 | | 46.2 | 14266 | 33.2 | 613 | FPC |
| Redondo | #1,2,3 | full | 200 | 363,000 | 323 | 14 | 39.2 | 20300 | 47.2 | 757 | FPC |
| | | 75% | | 272,000 | 306 | | 29.4 | 14540 | 33.8 | 620 | FPC |
| | | half | | 181,000 | 300 | | 19.6 | 9527 | 22.2 | 481 | FPC |
| | #4 | full | 200 | 181,000 | 323 | 14 | 19.6 | 10150 | 23.6 | 500 | FPC |
| | | 75% | | 136,000 | 306 | | 14.7 | 7270 | 16.9 | 409 | FPC |
| | | half | | 91,000 | 300 | | 9.8 | 4764 | 11.1 | 317 | FPC |
| | #5&6 | full | 200 | 505,000 | 274 | 12 | 74.5 | 24508 | 57.0 | 812 | FPC |
| | | 75% | | 379,000 | 255 | | 55.9 | 17166 | 39.9 | 685 | FPC |
| | | half | | 253,000 | 236 | | 37.3 | 10594 | 24.6 | 513 | FPC |
| | #7&8 | full | 200 | 1,291,000 | 230 | 17 | 94.8 | 52603 | 122.3 | 1047 | FPC |
| | | 75% | | 968,000 | 204 | | 71.1 | 34560 | 80.4 | 910 | FPC |
| | | half | | 646,000 | 180 | | 47.4 | 19794 | 46.0 | 746 | FPC |
| Long Beach | #1&2 | full | 247.5 | 500,000 | 300 | 16 | 42 | 26665 | 62.0 | 962 | FPC |
| | | 75% | | 375,000 | 250 | | 32 | 17132 | 39.8 | 745 | FPC |
| | | half | | 250,000 | 220 | | 20 | 9373 | 21.8 | 519 | FPC |
| | #3 | full | 247.5 | 250,000 | 290 | 16 | 21 | 12937 | 30.1 | 629 | FPC |
| | | 75% | | 187,000 | 240 | | 16 | 8220 | 19.1 | 479 | FPC |
| | | half | | 125,000 | 210 | | 10 | 4451 | 10.4 | 332 | FPC |
| | #4 | full | 247.5 | 520,000 | 320 | 16 | 44 | 29529 | 68.7 | 995 | FPC |
| | | 75% | | 390,000 | 260 | | 33 | 18360 | 42.7 | 776 | FPC |
| | | half | | 260,000 | 220 | | 21 | 9841 | 22.9 | 534 | FPC |
| Los Alamitos | #1&2 | full | 200 | 469,000 | 274 | 12 | 69.1 | 22731 | 52.9 | 791 | FPC |
| | | 75% | | 370,000 | 265 | | 54.5 | 17372 | 40.4 | 690 | FPC |
| | | half | | 262,000 | 258 | | 38.6 | 11990 | 27.9 | 552 | FPC |
| | #3&4 | full | 200 | 819,000 | 258 | 14 | 82.6 | 34923 | 81.2 | 913 | FPC |
| | | 75% | | 655,000 | 252 | | 66.1 | 27309 | 63.5 | 841 | FPC |
| | | half | | 491,000 | 227 | | 49.6 | 18407 | 42.8 | 714 | FPC |
| | #5&6 | full | 201.5 | 1,157,000 | 255 | 17 | 84.9 | 52325 | 121.7 | 1050 | FPC |
| | | 75% | | 983,350 | 250 | | 72.2 | 43636 | 101.5 | 989 | FPC |
| | | half | | 809,820 | 179 | | 65.9 | 27325 | 63.5 | 846 | FPC |
| Scattergood | #1&2 (common stack) | full | 300 | 543,000 | 308 | 20 | 59.5 | 60393 | 140.5 | 1436 | FPC |
| | | 75% | | 430,000 | 282 | | 48.2 | 45233 | 105.2 | 1304 | FPC |
| | | half | | 300,000 | 253 | | 30.4 | 25732 | 59.8 | 1081 | FPC |
| | #3 | full | 300 | 1,200,000 | 278 | 23.5 | 60 | 76722 | 178.4 | 1556 | FPC |
| | | 75% | | 970,000 | 253 | | 49 | 57263 | 133.2 | 1411 | FPC |
| | | half | | 650,000 | 230 | | 31 | 32870 | 76.4 | 1173 | FPC |
| Valley | #1&2 | full | 250 | 362,000 | 350 | 12.5 | 52 | 22919 | 53.3 | 921 | FPC |
| | | 75% | | 295,000 | 314 | | 42.4 | 17091 | 39.7 | 747 | FPC |
| | | half | | 190,000 | 220 | | 27.3 | 7809 | 18.2 | 467 | FPC |
| | #3&4 | full | 250 | 532,000 | 314 | 15 | 52.5 | 30474 | 70.9 | 1013 | FPC |
| | | 75% | | 382,000 | 285 | | 37.6 | 20041 | 46.6 | 821 | FPC |
| | | half | | 266,000 | 265 | | 26.2 | 13049 | 30.3 | 635 | FPC |

Table A4.1 (Continued)

| Generating Station | Unit Number | Plant Load | Physical Stack Height $H_s$ (ft) | Stack Volumetric Flow Rate (SCFM) | Stack Exhaust Temperature $T_s$ (°F) | Stack Diameter (ft) | Exhaust Gas Velocity $V_s$ (FPS) | Briggs $F$ ($ft^4/sec^3$) | Heat Flux $Q_H$ ($10^5$ cal/sec) | Plume Rise $\Delta H$ (ft) | Data Source |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Harbor | #1&2 | full | 247 | 243,200 | 338 | 8.7 | 77.5 | 16090 | 37.4 | 717 | FPC |
| | | 75% | | 172,500 | 302 | | 54.8 | 10347 | 24.1 | 550 | FPC |
| | | half | | 116,400 | 284 | | 38 | 6792 | 15.8 | 427 | FPC |
| | #3,4,5 | full | 247 | 365,000 | 339 | 9.7 | 89 | 23024 | 53.5 | 915 | FPC |
| | | 75% | | 282,000 | 309 | | 67 | 16041 | 37.3 | 715 | FPC |
| | | half | | 209,000 | 281 | | 51 | 11221 | 26.1 | 577 | FPC |
| Haynes | #1&2 | full | 240 | 585,000 | 260 | 13.2 | 75.5 | 28590 | 66.5 | 965 | FPC |
| | | 75% | | 445,000 | 236 | | 57.5 | 19761 | 46.0 | 801 | FPC |
| | | half | | 321,000 | 212 | | 41.4 | 12675 | 29.5 | 614 | FPC |
| | #3a,b | full | 240 | 302,500 | 263 | 10.5 | 62 | 15021 | 34.9 | 680 | FPC |
| | #4a,b | 75% | | 232,500 | 252 | | 47.8 | 11108 | 25.8 | 567 | FPC |
| | | half | | 162,500 | 235 | | 33.4 | 7231 | 16.8 | 438 | FPC |
| | #5&6 | full | 240 | 777,000 | 251 | 18.5 | 50.1 | 36001 | 83.7 | 1042 | FPC |
| | | 75% | | 510,000 | 234 | | 32.8 | 21947 | 51.0 | 883 | FPC |
| | | half | | 412,000 | 209 | | 27.6 | 16334 | 38.0 | 715 | FPC |
| Burbank | Magnolia | full | 66 | 34,500[4] | 375 | 5.5[5] | 24[4] | 2160 | 5.0 | 127 | FPC |
| | #1,2,3 | 75% | | 25,500[4] | 340 | | 18[4] | 1501 | 3.5 | 102 | FPC |
| | | half | | 17,000[4] | 310 | | 12[4] | 926 | 2.2 | 76 | FPC |
| | Magnolia | full | 150 | 164,856[4] | 315 | 10.0[5] | 35 | 9054 | 21.0 | 416 | FPC |
| | #4 | 75% | | 123,637[4] | 300 | | 26[4] | 6448 | 15.0 | 339 | FPC |
| | | half | | 82,425[4] | 290 | | 17[4] | 4173 | 9.7 | 261 | FPC |
| | Olive | full | 109 | 120,600[4] | 360 | 8 | 40 | 7383 | 17.2 | 324 | FPC |
| | #1 | 75% | | 90,450[4] | 330 | | 30[4] | 5164 | 12.0 | 261 | FPC |
| | | half | | 60,300[4] | 290 | | 20[4] | 3080 | 7.2 | 192 | FPC |
| | Olive | full | 109 | 120,600[4] | 245 | 8 | 40 | 5246 | 12.2 | 264 | FPC |
| | #2 | 75% | | 90,450[4] | 240 | | 30[4] | 3853 | 9.0 | 219 | FPC |
| | | half | | 60,300[4] | 235 | | 20[4] | 2514 | 5.8 | 170 | FPC |
| Glendale | #1a,b | full | 60 | 85,000[4] | 300[4] | 6 | 40[5] | 3571 | 8.3 | 165 | FPC |
| | 2 | 75% | | 62,000[4] | 275[4] | | 36[5] | 2971 | 6.9 | 148 | FPC |
| | | half | | 45,000[4] | 250[4] | | 27[5] | 2033 | 4.7 | 118 | FPC |
| | #3 | full | 80 | 92,000[4] | 300[4] | 6 | 54[5] | 4821 | 11.2 | 222 | FPC |
| | | 75% | | 70,000[4] | 275[4] | | 41[5] | 3383 | 7.9 | 179 | FPC |
| | | half | | 48,000[4] | 250[4] | | 28[5] | 2108 | 4.9 | 135 | FPC |
| | #4 | full | 100 | 160,000[4] | 300[4] | 8 | 53[5] | 8412 | 19.6 | 338 | FPC |
| | | 75% | | 122,000[4] | 250[4] | | 40[5] | 5354 | 12.5 | 258 | FPC |
| | | half | | 88,000[4] | 220[4] | | 29[5] | 3398 | 7.9 | 196 | FPC |
| | #5 | full | 100 | 160,000[4] | 180[4] | 8 | 53[5] | 4901 | 11.4 | 245 | FPC |
| | | 75% | | 122,000[4] | 160[4] | | 40[5] | 3158 | 7.3 | 188 | FPC |
| | | half | | 88,000[4] | 150[4] | | 29[5] | 2084 | 4.8 | 146 | FPC |
| Pasadena | Broadway | full | 120 | 190,000 | 371 | 10 | 40 | 11806 | 27.5 | 446 | FPC |
| | #1&2 | 75% | | 137,000 | 320 | | 29 | 7602 | 17.7 | 342 | FPC |
| | | half | | 93,000 | 276 | | 20 | 4600 | 10.7 | 253 | FPC |
| | Broadway | full | 140 | 174,000 | 211 | 5 | 74 | 3234 | 7.5 | 218 | FPC |
| | #3 | 75% | | 134,000 | 187 | | 57 | 2160 | 5.0 | 171 | FPC |
| | | half | | 92,000 | 132 | | 39 | 891 | 2.1 | 101 | FPC |
| | Glenarm | full | 86 | 78,660 | 370 | 6 | 24 | 2545 | 5.9 | 155 | FPC |
| | #14,15 | 75% | | 57,000 | 352 | | 17 | 1734 | 4.0 | 123 | FPC |
| | | half | | 39,520 | 309 | | 12 | 1099 | 2.6 | 94 | FPC |
| | Glenarm | full | 81 | 103,500 | 354 | 5.5 | 25 | 2152 | 5.0 | 137 | FPC |
| | #16,17 | 75% | | 75,000 | 310 | | 18 | 1389 | 3.2 | 106 | FPC |
| | | half | | 52,000 | 295 | | 12 | 887 | 2.1 | 81 | FPC |
| Huntington Beach | #1 | full | 203 | 1,203,000 | 275 | 17.3 | 85.6 | 58726 | 136.6 | 1097 | FPC |
| | | 75% | | 917,000 | 255 | | 65.3 | 41679 | 96.9 | 978 | FPC |
| | | half | | 621,000 | 230 | | 44.2 | 25399 | 59.1 | 829 | FPC |
| | #2 | full | 203 | 1,207,000 | 250 | 17.3 | 85.9 | 53764 | 125.0 | 1065 | FPC |
| | | 75% | | 919,000 | 230 | | 65.5 | 37639 | 87.5 | 946 | FPC |
| | | half | | 622,000 | 210 | | 44.3 | 23050 | 53.6 | 803 | FPC |

Table A4.1 (Continued)

| Generating Station | Unit Number | Plant Load | Physical Stack Height $H_s$ (ft) | Stack Volumetric Flow Rate (SCFM) | Stack Exhaust Temperature $T_s$ (°F) | Stack Diameter (ft) | Exhaust Gas Velocity $V_s$ (FPS) | Briggs F ($ft^4/sec^3$) | Heat Flux $Q_H$ ($10^5$ cal/sec) | Plume Rise ΔH (ft) | Data Source |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mandalay | #1 | full | 200 | 1,081,482 | 229[4] | 17.3 | 77 | 44044 | 102.4 | 987 | FPC |
| | | 75% | | 840,426 | 216[4] | | 60 | 32217 | 74.5 | 889 | FPC |
| | | half | | 599,370 | 202[4] | | 43 | 21400 | 49.8 | 776 | FPC |
| Etiwanda | #1&2 | full | 176 | 384,000 | 265 | 12 | 57 | 18169 | 42.3 | 673 | FPC |
| | | 75% | | 292,000 | 245 | | 43 | 12690 | 29.5 | 543 | FPC |
| | | half | | 196,000 | 225 | | 29 | 7833 | 18.2 | 406 | FPC |
| | #3&4 | full | 199 | 861,000 | 260 | 14 | 93 | 39616 | 92.1 | 949 | FPC |
| | | 75% | | 650,000 | 235 | | 70 | 26943 | 62.7 | 835 | FPC |
| | | half | | 440,000 | 210 | | 48 | 16356 | 38.0 | 664 | FPC |
| Highgrove | #1&2 | full | 70 | 108,000 | 334 | 8.2 | 34 | 6210 | 14.4 | 244 | FPC |
| | | 75% | | 83,000 | 318 | | 26 | 4559 | 10.6 | 203 | FPC |
| | | half | | 56,000 | 302 | | 17 | 2851 | 6.6 | 153 | FPC |
| | #3&4 | full | 99 | 150,000 | 312 | 10 | 32 | 8211 | 19.1 | 332 | FPC |
| | | 75% | | 115,000 | 296 | | 24 | 5882 | 13.7 | 272 | FPC |
| | | half | | 78,000 | 238 | | 17 | 3382 | 7.9 | 195 | FPC |
| San Bernardino | #1 | full | 130 | 10,810 | 285 | 10 | 2.3 | 545 | 1.3 | 73 | FPC |
| | | 75% | | 8,730 | 263 | | 1.9 | 418 | 1.0 | 62 | FPC |
| | | half | | 5,440 | 240 | | 1.2 | 241 | 0.6 | 45 | FPC |
| | #2 | full | 130 | 10,510 | 285 | 10 | 2.2 | 521 | 1.2 | 71 | FPC |
| | | 75% | | 7,890 | 263 | | 1.7 | 374 | 0.9 | 58 | FPC |
| | | half | | 5,250 | 240 | | 1.1 | 221 | 0.5 | 42 | FPC |
| Ormond Bench | #1&2 (gas) | full | 237 | 2,080,000 | 251 | 22 | 91 | 92474 | 215.1 | 1415 | FPC |
| | | 75% | | 1,688,000 | 225 | | 74 | 67177 | 156.2 | 1272 | FPC |
| | | half | | 1,130,000 | 203 | | 50 | 40472 | 94.1 | 1074 | FPC |
| | #1&2 (oil) | full | 237 | 1,728,000 | 255 | 22 | 76 | 78455 | 182.4 | 1339 | FPC |
| | | 75% | | 1,222,000 | 229 | | 54 | 49950 | 116.2 | 1152 | FPC |
| | | half | | 864,000 | 206 | | 38 | 31283 | 72.8 | 986 | FPC |
| Large Interruptible Gas Customers | | | | | | | | | | | |
| UCLA boilers (5 stacks) | | | 45 | 30,000 | 500 | 4.5 | 31 | 4372 | 10.2 | 166 | c |
| UCLA boiler (1 stack) | | | 45 | 40,000 | 500 | 5 | 34 | 5920 | 13.8 | 199 | c |

Table A4.1 (Continued)

| Source Type | Physical Stack Height $H_s$ (ft) | Stack Volumetric Flow Rate (SCFM) | Stack Exhaust Temperature $T_s$ (°F) | Stack Diameter (ft) | Exhaust Gas Velocity $V_s$ (FPS) | Briggs F ($ft^4/sec^3$) | Heat Flux $Q_H$ ($10^5$ cal/sec) | Plume Rise ΔH (ft) | Data Source |
|---|---|---|---|---|---|---|---|---|---|
| **Chemical Plants** | | | | | | | | | |
| Sulfur Recovery Plants | | | | | | | | | |
| ARCO | 200 | 25,200 | 1140 | 5.5 | 54 | 8785 | 20.43 | 458 | KVB |
| Champlin | 50 | 3,720 | 1130 | 2.8 | 30 | 1261 | 2.93 | 82 | KVB |
| Douglas | 60 | 2,843 | 850 | 2.2 | 29 | 673 | 1.56 | 61 | KVB |
| Gulf | 100 | 36,738 | 147 | 4 | 36 | 627 | 1.46 | 71 | KVB |
| Mobil | 150 | 35,700 | 1100 | 6.5 | 70 | 15707 | 36.5 | 578 | KVB |
| Standard (3 stacks) | 150 | 8,100 | 120 | 2.4 | 32 | 141 | 0.33 | 34 | KVB |
| Texaco | 160 | 9,912 | 190 | 1.6 | 100 | 396 | 0.92 | 65 | KVB |
| Union (2 stacks) | 171 | - | 120 | 5.0 | 20 | 383 | 0.89 | 66 | a |
| Powerine | 100 | (exhausts through FCC unit stack; see below) | | | | | | 215 | |
| Sulfuric Acid Plants | | | | | | | | | |
| Standard Oil | 150 | 16,400 | 160 | 4 | 26 | 513 | 1.19 | 74 | KVB |
| Collier | 80 | 26,736 | 85 | 3.1 | 60 | 174 | .41 | 30 | KVB |
| Stauffer #3 | 200 | 18,524 | 130 | 3.4 | 37 | 380 | .88 | 70 | KVB |
| **Petroleum Refining and Production** | | | | | | | | | |
| Fluid Catalytic Crackers | | | | | | | | | |
| ARCO (each of two) | 89 | 108,000 | 430 | 6 | 100 | 11830 | 27.5 | 396 | KVB |
| Gulf | 101 | 51,441 | 450 | 5 | 73 | 6187 | 14.4 | 282 | KVB |
| Mobil (each of two) | 100 | 110,600 | 600 | 9 | 59 | 19317 | 44.9 | 557 | KVB |
| Powerine | 100 | 32,410 | 440 | 7.9 | 19 | 3958 | 9.2 | 215 | KVB |
| Shell | 100 | 143,651 | 520 | 10.3 | 57 | 22490 | 52.3 | 497 | KVB |
| Standard | 150 | 195,500 | 730 | 13.5 | 51 | 41590 | 96.7 | 794 | KVB |
| Texaco (each of two) | 181 | 136,500 | 485 | 9.1 | 64 | 18871 | 43.9 | 696 | KVB |
| Union | 140 | 91,500 | 1640 | 10.3 | 72 | 45848 | 106.6 | 788 | KVB |
| | 140 | 110,200 | 750 | 9.5 | 59 | 24136 | 56.1 | 637 | KVB |
| Misc. Petroleum Industry Equipment | | | | | | | | | |
| ARCO odor incinerator (FLARE) | 130 | 16,200 | 1580 | 5.5 | 45 | 8090 | 18.8 | 367 | KVB |
| **Misc. Stationary Sources** | | | | | | | | | |
| Petroleum Coke Kilns | | | | | | | | | |
| Great Lakes #2,3,4 | 150 | 13,700 | 1400 | 13.5 | 55 | 57581 | 133.9 | 1261 | KVB |
| Glass Furnaces | | | | | | | | | |
| Anchor Hocking #3 | 75[2] | 15,054 | 850 | 6 | 22 | 3800 | 8.8 | 187 | KVB |
| Ball #1 | 60 | 26,877 | 680 | 6.5 | 28 | 5110 | 11.9 | 204 | KVB |
| Brockway | 58 | 27,800 | 630 | 5.2 | 46 | 5163 | 12.0 | 203 | KVB |
| Glass Containers 1 | 72 | 13,000 | 160 | 3.1 | 37 | 439 | 1.0 | 50 | KVB |
| Glass Containers 2 | 72 | 23,000 | 540 | 4.2 | 52 | 3490 | 8.1 | 175 | KVB |
| Latchford A | 120 | 12,100 | 720 | 4.0 | 37 | 2631 | 6.1 | 181 | KVB |
| Latchford B | 80 | 5,240 | 560 | 4.0 | 13 | 808 | 1.9 | 76 | KVB |
| Latchford C | 100 | 11,443 | 720 | 3.8 | 34 | 2182 | 5.0 | 151 | KVB |
| Latchford D | 68 | 10,500 | 800 | 3.1 | 54 | 2424 | 5.6 | 137 | KVB |
| Owens Illinois (Vernon) 23A | 82 | 15,000 | 740 | 3.5 | 61 | 3366 | 7.8 | 180 | KVB |
| Owens Illinois (Vernon) 23B | 94 | 16,363 | 760 | 4.5 | 38 | 3510 | 8.2 | 195 | KVB |
| Owens Illinois (Vernon) 23C | 69 | 7,000 | 680 | 4.50 | 17 | 1487 | 3.5 | 103 | KVB |
| Owens Illinois (Vernon) 23D | 58 | 8,000 | 652 | 3.46 | 32 | 1619 | 3.8 | 101 | KVB |
| Reichhold | 80 | 3,860 | 1420 | 2.42 | 52 | 1757 | 4.0 | 121 | KVB |
| Thatcher #1 | 40 | 14,000 | 900 | 4.21 | 43 | 3746 | 8.7 | 144 | KVB |
| Thatcher #2 | 80 | 15,000 | 590 | 3.42 | 54 | 2529 | 5.9 | 150 | KVB |
| Thatcher #3 | 70 | 15,000 | 600 | 3.42 | 54 | 2553 | 5.9 | 143 | KVB |
| Metals | | | | | | | | | |
| (a) Primary Metals (steel mill) | | | | | | | | | |
| Kaiser Fontana | | | | | | | | | |
| Sinter plant (2) | 300 | 129,000 | 240 | 7.5 | 80 | 9031 | 21.0 | 548 | KVB |
| Coke ovens A-E (5) | 225 | 58,800 | 450 | 16 | 8.5 | 7376 | 17.2 | 432 | KVB |
| Coke ovens F-G (1) | 250 | 45,000 | 450 | 16 | 6.5 | 5641 | 13.1 | 384 | KVB |
| Open hearth 1-9 (8) | 175 | 40,600 | 500 | 4.5 | 80 | 5881 | 13.7 | 341 | KVB |

Table A4.1 (Continued)

| | Physical Stack Height $H_s$ (ft) | Stack Volumetric Flow Rate (SCFM) | Stack Exhaust Temperature $T_s$ (°F) | Stack Diameter (ft) | Exhaust Gas Velocity $V_s$ (FPS) | Briggs F ($ft^4/sec^3$) | Heat Flux $Q_H$ ($10^5$ cal/sec) | Plume Rise $\Delta H$ (ft) | Data Source |
|---|---|---|---|---|---|---|---|---|---|
| (b) Secondary Metals (lead furnaces) | | | | | | | | | |
| RSR-Quemetco | | | | | | | | | |
| Reverb | 60 | 11,700 | 510 | note(3) | note(3) | - | - | - | KVB |
| Cupola | 60 | 6,410 | 240 | note(3) | note(3) | - | - | - | KVB |
| NL Industries | | | | | | | | | |
| Cupola | 50 | | | | | | | | |
| Cupola | 50 | | | | | | | | |
| Mineral Products | | | | | | | | | |
| Crestlite (aggregate kiln) | 25 | 46,000 | 130 | 8 | 15 | 3865 | 9.0 | 122 | KVB |
| Sewage Treatment Plant Digesters | | | | | | | | | |
| Hyperion Sewage Treatment Plant (7 stacks) | 35 | 6,700 | 600 | 1 | 142 | 1013 | 2.3 | 62 | b |

Notes

Key to Data Sources

(1) KVB: Hunter, 1975
FPC: Thomas, 1976
a: Jones, 1976
b: Rojas, 1976
c: UCLA, 1976

(2) assumed
(3) baghouse
(4) estimated by utility
(5) calculated
- not available

## A4.4 Generalization of Plume Rise Calculations

The plume rise calculations given in Table A4.1 provide a basis for visualizing the relative buoyancy of plumes from various sources for which stack data were available. Most major $SO_x$ sources in the basin are represented in that table. However, there are literally thousands of emission sources in the Los Angeles basin for which stack data are unavailable. In order to progress with air quality modeling calculations, some assumptions must be made which will assign a physical stack height and plume rise to each source in the airshed.

The approach taken here will be to use the data from sources for which the stack parameters are known to assign a typical stack height and plume rise behavior to all members of a single source class. Since the source classes defined in Appendix A2 to this study are based on similarity of equipment type, the use of source class averaged plume rise behavior should be a reasonable and practical approach.

Physical stack height and plume rise above the physical stack is summarized for each source class of our emission inventory in Table A4.2. Values given are for the same set of reference atmospheric conditions as in Table A4.1. The range of values apparent for sources analyzed in Table A4.1 is stated, along with a choice of typical values to represent the source class as a whole. Typical values given in Table A4.2 are usually the arithmetic mean of the stack heights and plume rises calculated for members of each source class in Table A4.1. In those cases where no data are available in Table A4.1 upon which to

# TABLE A4.2

## Stack Height and Plume Rise for Individual Source Classes

(estimated at reference conditions: neutral stability; ambient temperature 64.4°F; wind speed 6.2 mph)

| | Number of Cases Examined in Table A4.1 | Notes | Range of Physical Stack Heights (ft) | Typical Physical Stack Height Adopted $H_s$ (ft) | Range of Plume Rise Calculated at Reference Conditions (ft) | Typical Plume Rise Adopted at Reference Conditions $\Delta H$ (ft) | Effective Stack Height Adopted at Reference Conditions $H_s + \Delta H$ (ft) |
|---|---|---|---|---|---|---|---|
| **Stationary Sources** | | | | | | | |
| Fuel Combustion | | | | | | | |
| Electric Utilities at 75% of Full Load | | | | | | | |
| Large Generating Units (H > 150 ft) | 28 | | 176-300 | 225 | 409-1411 | 822 | 1047 |
| Small Generating Units (H ≤ 150 ft) | 16 | | 60-150 | 102 | 58 - 342 | 189 | 291 |
| Refinery Fuel Burning | -- | (b) | | 100 | | 180 | 280 |
| Other Interruptible Gas Customers (Large) | 2 | | 45 | 45 | 166 - 199 | 182 | 227 |
| Firm Gas Customers | -- | (c) | | 12 | | 24 | 36 |
| Chemical Plants | | | | | | | |
| Sulfur Recovery Plants | 9 | | 50-200 | 127 | 61 - 578 | 181 | 308 |
| Sulfuric Acid Plants | 3 | | 80-200 | 143 | 30 - 74 | 58 | 201 |
| Other Chemicals | -- | (c) | | 35 | | 70 | 105 |
| Petroleum Refining and Production | | | | | | | |
| Fluid Catalytic Crackers | 9 | | 89-181 | 122 | 282 - 794 | 540 | 662 |
| Sour Water Strippers | -- | (d) | | 130 | | 367 | 497 |
| Delayed Cokers | -- | (d) | | 130 | | 367 | 497 |
| Miscellaneous Refinery Processes | -- | (d) | | 130 | | 367 | 497 |
| Oil Field Production | -- | (c) | | 20 | | 72 | 92 |
| Miscellaneous Stationary Sources | | | | | | | |
| Petroleum Coke Calcining Kilns | 1 | | 150 | 150 | 1261 | 1261 | 1411 |
| Glass Furnaces | 17 | | 40-120 | 75 | 50 - 204 | 147 | 222 |
| Secondary Metals Industries (On-Grid) | 4 | (a) | 50 - 60 | 55 | | 110 | 165 |
| Sewage Treatment Plant Digesters | 1 | | 35 | 35 | 62 | 62 | 97 |
| Other Industrial Processes | -- | (c) | | 35 | | 70 | 105 |
| Permitted Incinerators | -- | (c) | | 35 | | 70 | 105 |
| Primary Metals Industries (Off-Grid Steel Mill) | 4 | | 175-300 | 238 | 341 - 548 | 426 | 664 |
| Mineral Products Industries (Off-Grid) | 1 | | 25 | 25 | 122 | 122 | 147 |
| **Mobile Sources** | | | | | | | |
| Autos and Light Duty Trucks | -- | (b) | | 1 | | 2 | 3 |
| Heavy Duty Vehicles | -- | (b) | | 12 | | 24 | 36 |
| Airport Operations | -- | (b) | | 20 | | 40 | 60 |
| Shipping Operations | -- | (b) | | 90 | | 180 | 270 |
| Railroad Operations | -- | (b) | | 18 | | 36 | 54 |

Notes: (a) Physical stack height known; plume rise assumed.

(b) Physical stack height estimated by observation of members of that source class; plume rise assumed.

(c) Physical stack height and plume rise assumed.

(d) Based on data for one refinery flare given in Table A4.1.

base a stack parameter characterization for a given source class, an assumed value has been entered in Table A4.2 based on a qualitative impression of the size of the sources involved.

The plume rise values given in Tables A4.1 and A4.2 are for a single set of reference atmospheric conditions. An air quality modeling exercise which attempted to treat every source in detail could, on the basis of stack parameters given in Table A4.1, recompute effective stack height at each time of day for each source. Changes in power plant load with time of day could be factored into the plume rise calculations. Adjustments for changing wind speed and atmospheric temperature could be made. If greater information were available on atmospheric temperature structure, more complex plume rise formulas could be adopted which incorporate corrections for changing atmospheric stability. However, for the long time period which we intend to simulate (three years), and the large number of sources involved (several thousand), inclusion of such great detail is not practical within a small computing budget. Instead, the following approach seems reasonable.

The plume rise formulas of equations A4.3 and A4.4 are strict inverse functions of ambient wind speed, U, and only weakly depend on changes in buoyancy flux, F. Fortunately, ambient wind speed data are readily available at each hour of the day. Therefore, a practical approach to dynamically allocating source effective stack height would seem to be as follows:

$$H(t,i) = H_s(i) + \frac{U_{ref}}{U(t)} \cdot \Delta H_{ref}(i) \qquad \text{(A4.5)}$$

The effective source height, H(t,i), at time t for source class i will be taken as that source's typical physical stack height, $H_s(i)$, plus that source's plume rise at reference conditions scaled by the ratio of reference wind speed to the actual wind speed at time t.

## REFERENCES FOR APPENDIX A4

Briggs, G.A. (1971), "Plume Rise: A Recent Critical Review," Nuclear Safety, Vol. 12, No. 1.

Hunter, S.C. (1975), KVB Incorporated, personal communication, November 19, 1975.

Hunter, S.C. and N.L. Helgeson (1976), Control of Oxides of Sulfur from Stationary Sources in the South Coast Air Basin of California, KVB Incorporated, Tustin, California.

Jones, H. (1976), Union Oil Co., personal communication, June 22, 1976.

National Oceanic and Atmospheric Administration (1974), Climates of the States, Port Washington, N.Y., Water Information Center.

Rojas, R. (1976), Hyperion Sewage Treatment Plant, personal communication, June 17, 1970.

Thomas, M.F. (1976), Federal Power Commission, personal communication, February 20, 1976.

UCLA (1976), steam plant personnel, personal communication, June 24, 1976.

# APPENDIX B

## APPENDICES TO THE

## BASELINE AIR QUALITY CHARACTERIZATION

# APPENDIX B1

## ROUTINE AIR MONITORING PROGRAMS FOR SULFUR DIOXIDE AND SULFATES

### B1.1 The Los Angeles Air Pollution Control District Air Monitoring Program: 1965-1974

Total suspended particulate matter samples have been collected by the Los Angeles Air Pollution Control District by high volume sampling on a regular basis since August 1965. The sampling period was twenty-four hours in duration, at a sample flow rate of 990 to 1270 liters/min (35 to 45 cfm). Samples were collected on glass fiber filters from which water-soluble sulfates were determined by the turbidimetric method. From August 1965 through August 1970, samples were taken from 8:00 a.m. to 8:00 a.m. at intervals ranging from weekly to twice weekly to every fifth day. From September 1970 through the end of 1974, samples were taken from midnight to midnight at least at five day intervals, with a strict five-day sampling schedule prevailing from July 1971 until the end of 1974.

Figure 2.3 in the body of this report shows the location of eight Los Angeles County sulfate air monitoring stations in existence at the end of 1974. The stations at downtown Los Angeles, West Los Angeles, and Lennox have been operated at the same location since August 1965. Sampling commenced at Reseda in late 1967, and at Pasadena and Azusa in July 1971. In January 1974, a monitoring station was added at Lynwood. The APCD also sampled for sulfates at one desert location, Lancaster, outside of the South Coast Air Basin.

Filter type is an important consideration when sampling for sulfates. It has been reported that several percent of the sulfate collected using glass fiber filters may be due to sulfur dioxide gas converted to sulfates on the surface of the filters (Lee and Wagman, 1966). A change in filter type could affect sulfate concentration measurements by altering the extent of this artifact sulfate formation. From 1965 through early 1967, APCD samples were collected on a variety of filter types: MSA 1106 BH; Gelman E, and Gelman A glass fiber filters. From late 1967 through 1974, all samples were reported to be collected on Gelman A filters. The Los Angeles APCD laboratory procedures followed the standard Public Health Service turbidimetric method (U.S. Public Health Service, 1962). Filters are quartered, and water-soluble sulfates are extracted by refluxing the quarter-filter in deionized water for one-and-one-half hours. Sulfate then is precipitated with barium ion in a dilute hydrochloric acid-glycerine-alcohol solution. Light attenuation through the turbid suspension thus formed is measured with a spectrophotometer at a wavelength of 500 nm. Sulfate concentration then is determined by reference to a calibration chart constructed from analysis of known sodium sulfate standard solutions. A quality control study of the accuracy and precision of sulfate measurements made by the LAAPCD laboratories was conducted by Porter et al. (1976). They report an accuracy (coefficient of variation expressed as a percentage) of turbidimetric method sulfate determination made from reference filter strips which averages 11% of the sulfate level being measured, and a precision on standard solutions of

11.8%. The APCD sulfate sampling program is described further by Wadley and MacPhee (1976).

Sulfur dioxide samples also were taken by the LAAPCD at each of their sulfate air monitoring locations.[1] Continuous monitoring instruments employing the conductometric method are used (Thomas, Ivie, and Fitt, 1946). Sulfur dioxide is reacted with an absorbing reagent of hydrogen peroxide (0.003M) and sulfuric acid (0.00005 N) in deionized water. The absorbed sulfur dioxide is oxidized to sulfuric acid, and the increase in conductivity of the solution is measured. Calibration is performed under both static and dynamic conditions. Static calibration involves addition of known amounts of sulfuric acid to the reagent, while dynamic calibration involves simultaneous sampling of sulfur dioxide - air mixtures by both the conductometric and West-Gaeke (1956) methods.

Normal $SO_2$ instrument range is 0 to 5 ppm on a linear scale. Instrument response is recorded on a continuous strip chart which is later read by a data entry technician and transferred to digital form as an average $SO_2$ concentration for each hour. The minimum $SO_2$ concentration discernible on these strip charts is 0.01 ppm (26 $\mu gm/m^3$). All $SO_2$ concentrations below that value also would be reported as 0.01 ppm. At the low $SO_2$ concentrations present in some portions of Los Angeles County, the APCD instruments encounter concentrations at

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[1] Sulfur dioxide is also monitored at some locations not equipped for sulfate sampling.

or below their minimum detection limit much of the time. Twenty-four hour averages constructed on days at which the $SO_2$ instruments measured concentrations below their minimum detection limit thus would be biased high.

## B1.2 The Community Health and Environmental Surveillance System (CHESS) Air Monitoring Program: 1972-1974

As part of an effort to assess the health effects of air pollutants in Los Angeles smog, the U.S. Environmental Protection Agency established a series of air monitoring stations in seven Southern California communities in early 1972. These CHESS station locations are shown in Figure 2.3 in the main body of this report.

Total suspended particulate matter samples were collected daily by high volume sampling. The sampling period was twenty-four hours in duration at a sample flow rate of 1130 to 1700 liters/min (40 to 60 cfm). Samples were collected on Gelman A glass fiber filters. Monitoring stations were operated by contractors. Each twenty-four hour sampling period nominally began at 11:00 a.m. daily. The actual time of sample change at a given station may have been as early as 8:00 a.m. or as late as 1:00 p.m. (personal communication, Duckworth, 1976). Sulfate sampling commenced at Vista, Glendora and Anaheim in late January 1972. The sulfate data base at the remaining CHESS air monitoring stations began in early May 1972.

The intended sulfate anlaysis throughout the sampling program followed the automated methylthymol blue procedure (see Barnard et al., 1976). A strip cut from each filter is refluxed in distilled water,

and the resulting extract is passed through a cation-exhange column to remove interferences. The sample is then reacted with a solution containing barium chloride and methylthymol blue at a known concentration. Sulfate present reacts to form barium sulfate. Excess barium then reacts with the methythymol blue to form a chelate. The amount of dye remaining is dependent on the amount of barium previously removed as barium sulfate, and provides a means of assessing the amount of sulfate initially present in the solution. Colorimetric measurements are made using a Technion Autoanalyzer. Barnard et al. (1976) state that "The precision and accuracy (of this method) depends upon the region of the absorbance vs. concentration curve in which work is being done."

While the intended laboratory procedures were the same over the period 1972 through 1974, the actual laboratory performing the analyses was changed a number of times. In a retrospective study of laboratory performance, it was found that sulfate analyses reported from October 1972 through May 1974 were probably in error (Heiderscheit and Hertz, 1977). Collaborative reanalysis of more than two hundred archived filters by three different laboratories indicated that the October 1972 through May 1974 sulfate values originally reported should be multiplied by 1.51 in order to match the results of the filter reanalysis. This correction factor was found to be independent of sulfate concentration. In spite of this scale correction, the originally reported October 1972 through May 1974 CHESS sulfate data correlated only 0.86 with the results of the filter reanalysis. CHESS sulfate

data reported during that period of time may be less accurate and precise than normally would result from the sampling procedures intended.

Explicit determination of the accuracy and precision of sulfate measurements made by the CHESS network is unreported. However, given the known laboratory problems, it is likely that sampling errors were larger than would normally be expected from the methods employed. Therefore, a study was conducted as part of this research project in an attempt to set a bound on CHESS sulfate sampling accuracy.

The Anaheim and Garden Grove CHESS monitoring sites are located less than two miles apart. That distance is less than the characteristic dimensions of the grid system to be used in our forthcoming air quality modeling study. Thus these two monitoring locations could have been represented by a single sulfate air quality prediction (if desired) when establishing our modeling grid network. Given the close proximity of these two monitoring sites, and the fact that sulfate concentration gradients are observed to be rather uniform over the South Coast Air Basin, the working hypothesis was adopted that simultaneous sulfate samples taken at Garden Grove and Anaheim could be thought to represent two independent attempts to measure the same event by the CHESS standard operating procedure. The coefficient of variation (standard error divided by mean concentration) was determined within each pair of samples representing 830 days of record during 1972 through 1974. The average coefficient of variation was 0.254 (25.4 percent), with highest coefficient of variation in the range

below 5 $\mu gm/m^3$ and generally lower coefficients of variation above 10 $\mu gm/m^3$. This compares to an average accuracy of 3.9 percent on reference filter strips and precision of 1.8 percent on standard solutions obtained using the methythymol blue method at the Southern California APCD laboratories (Porter et al., 1976). That is hardly an exact comparison because the CHESS stations are not located immediately adjacent to each other, and the coefficient of variation for the CHESS data is wrapped around both sample collection, handling, analysis and data reduction, while the APCD measurement errors represent laboratory performance only. Nevertheless, the scatter introduced into individual CHESS samples by measurement errors is higher than usually expected. It will be seen in Appendix B4 that this problem was compensated for by the relatively dense (daily) CHESS sampling schedule, and that the CHESS data are still a useful resource for comparison to monthly mean sulfate predictions as long as the filter reanalysis reported by Heiderscheit and Hertz (1977) succeeded in removing any systematic bias to the mean.

Twenty-four hour average sulfur dioxide measurements also were taken at the same time and locations as the CHESS sulfate samples. A procedure similar to the West-Gaeke method was used (West and Gaeke, 1956; see also Barnard et al. (1976) and Benson et al. (1974) for description of CHESS modifications). Air containing sulfur dioxide is bubbled through a tetrachloromercurate (TCM) solution to form a solution of dichlorosulfitomercurate. The exposed absorbing reagent is then removed from the bubbler box at the sampling station and sent

to a laboratory for further processing. The dichlorosulfitomercurate ion is subject to slow decomposition. Thus control of the time-temperature history of samples from collection through laboratory processing is important. If proper sample handling procedures are not maintained, a loss of $SO_2$ is apparent and reported $SO_2$ values could be below the actual ambient concentrations.

At the laboratory, the exposed absorbing reagent is reacted with formaldehyde and acid-bleached pararosaniline hydrochloride to form a solution the color of which is dependent on the amount of sulfur dioxide collected. Until October 1972, colorimetric determinations were made by manual methods. After that date, a Technicon Autoanalyzer was used for this purpose. From January 1972 through the end of 1973, samples were collected in 35 ml of absorbing TCM solution at an air flow rate of 500 ml/min. It was reported that this solution volume and flow rate combination implies a combined sampling and analysis error of ± 10 percent at $SO_2$ concentrations below 26 $\mu gm/m^3$, with improved accuracy above 26 $\mu gm/m^3$ (Benson, et al., 1974, Appendix A). Later publications from the CHESS program (Barnard, et al., 1976) disclaim any great accuracy below 25 $\mu gm/m^3$. They state that while instrument response may be recorded as low as 4 $\mu gm/m^3$, sample values below 25 $\mu gm/m^3$ must be viewed as below minimum detection limits unless sample collection efficiency at very low concentrations has been established. In December 1973, $SO_2$ sampling commenced using a reduction in air flow rate to 200 ml/min and an increase in absorbing solution volume to 50 ml per sample. This change in sample volume and

air flow rate might affect $SO_2$ collection efficiency at the low $SO_2$ concentrations encountered in Los Angeles. Minimum detection limits might also have been affected.

CHESS sampling methods are further described by Benson et al. (1974, see their Appendix A). and by Barnard et al. (1976).

### B1.3 The National Air Surveillance Network (NASN) Air Monitoring Program: 1972-1974

Total suspended particulate samples have been collected by the National Air Surveillance Network by high volume sampling at locations in Southern California since the mid-1950's. Monitoring stations active during the period 1972 through 1974 are shown in Figure 2.3 in the main body of this report. With one exception, a three year record of sulfate monitoring data can be obtained at each of these NASN locations for the period 1972 through 1974. Sulfate data at Riverside seem unavailable for the years 1973 and 1974.

During the three years of interest to us, NASN stations were operated by volunteers on about 25 pre-selected days per year. The sampling period was midnight to midnight at an air flow rate of 1130 to 1700 liters/min (40 to 60 cfm). Gelman A glass fiber filters were used. Water soluble sulfates were determined by the methylthymol blue procedure.

Sulfur dioxide samples were taken concurrently with the sulfate samples at most NASN locations. Stations apparently not reporting sulfur dioxide data during the period 1972 through 1974 were Burbank,

Ontario and Riverside. Sulfur dioxide sampling followed the methods prescribed in the Federal Register (see Vol. 36, No. 84, April 30, 1971). Air is bubbled at a rate of 200 ml/min through 50 ml of a tetrachloromercurate absorbing reagent. Collected samples are shipped to a laboratory where $SO_2$ concentration is determined by the West-Gaeke procedure (West and Gaeke, 1956) as modified for the Autoanalyzer by Welch and Terry (1960). Comments made when discussing the CHESS $SO_2$ data concerning sample deterioration between field collection and laboratory analysis also apply to the NASN data. The nominal minimum detection limit of the Federal reference method is 25 $\mu gm/m^3$ although the NASN network attempts to report numerical results well below that value.

The NASN sampling methodology is described by Benson et al. (1974, see their Appendix B).

### B1.4 A Brief Comparison of Monitoring Methods

Each of these three monitoring agencies collected twenty-four hour average total suspended particulate samples by high volume sampling. In all cases during the years 1972 through 1974, the collection media were Gelman A glass fiber filters from which water soluble sulfates were extracted by refluxing with distilled or deionized water. The CHESS and NASN programs determined sulfate concentrations in these extracts by the automated methylthymol blue procedure. The LAAPCD's laboratory procedures followed the manual turbidimetric method. Recent comparative studies indicate that, when properly executed, these two

analytical methods yield generally comparable results at normal atmospheric sulfate levels (for example, see Porter, et al., 1976). Sulfate determinations by the two methods are highly correlated and typically differ by less than ten percent. However, at very low ambient sulfate concentrations approaching 1.5 $\mu gm/m^3$, the two methods may not be equivalent, with the turbidimetric method as practiced by the LAAPCD becoming subject to larger percentage errors (Porter et al., 1976). Very low sulfate concentrations are infrequent in the South Coast Air Basin, so this difficulty with the turbidimetric method is not of major practical concern. Sulfate sampling and analysis methods used by these agencies should yield nearly equivalent results. The CHESS program is known to have encountered some analytical problems in practice. Laboratories performing their analyses were changed several times between January 1972 and December 1974. As a result of a retrospective reanalysis of high volume sampler filters taken from late September 1972 through early June 1974, CHESS states that their raw sulfate data reported for that period must be multiplied by 1.51 in order to correct for a systematic laboratory error.

A notable difference between sulfate data bases lies in the sampling schedules employed. During the period 1972 through 1974, the LAAPCD and NASN networks sampled from midnight to midnight. The CHESS network 24-hour sampling period nominally began at 11:00 a.m., but start times at individual stations were said to vary between 8:00 a.m. and 1:00 p.m. CHESS samples were taken daily. The LAAPCD sampled for

sulfates once every five days, while the NASN program collected about twenty-five samples per year at each station location.

An attempt has been made to assess the coefficient of variation of sulfate samples representing the same monitoring event. The average coefficient of variation of the CHESS sulfate samples is thought to be about 0.25 based on comparison of data at two adjacent monitoring sites. The average coefficient of variation due to laboratory analyses by the LAAPCD is about 0.11. It has been shown elsewhere that variation of analyses within laboratories is the major cause of variance in duplicate sulfate determinations in the presence of proper sample handling (Evans, 1977). Therefore the overall coefficient of variation of the LAAPCD sulfate method probably also averages about 0.11. No estimates were found for the coefficient of variation of the NASN sulfate measurements. From the laboratory method employed, the NASN data might be quite accurate, but their volunteer-operated network undoubtedly suffers from sample custody problems of uncertain magnitude. It will be assumed that the NASN measurement system has a coefficient of variation due to sampling errors of 0.11, similar to the LAAPCD method. There is no point in pursuing the accuracy of the NASN analyses much further, as it will be seen from the discussion of Appendix B4 that the NASN's sampling schedule is so sparse that atmospheric fluctuations dominate the confidence interval on mean values constructed from NASN data.

Sulfur dioxide sampling methods employed by separate monitoring agencies are judged to be significantly different. The Los Angeles Air

Pollution Control District never reports $SO_2$ concentrations lower than 26 $\mu gm/m^3$ due to minimum detection limit problems with their conductometric instruments. Since 24-hour average $SO_2$ concentrations at or below 26 $\mu gm/m^3$ are typical in many areas of the South Coast Air Basin, *average $SO_2$ results reported by the LAAPCD are almost surely higher than actual*. CHESS and NASN stations employed the West-Gaeke colorimetric method. While the nominal minimum detection limit of that method is about the same as the conductometric method, attempts are made to estimate concentrations below 26 $\mu gm/m^3$. CHESS and NASN data thus have the possibility of representing true average $SO_2$ concentrations. However, sample handling and collection efficiency problems can arise with the West-Gaeke method which result in underestimation of $SO_2$ concentrations. *NASN and CHESS data thus represent a lower limit to likely actual $SO_2$ concentrations.*

## REFERENCES FOR APPENDIX B1

Barnard, W.D. et al. (1976), Community Health Environmental Surveillance Studies (CHESS) Air Pollution Monitoring Handbook: Manual Methods, Research Triangle Park, North Carolina, Health Effects Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency Publication EPA-600/1-76-011.

Benson, F.B. et al. (1974), Health Consequences of Sulfur Oxides: A Report from CHESS, 1970-1971, Research Triangle Park, North Carolina, Office of Research and Development, U.S. Environmental Protection Agency Publication EPA-650/1-74-004. See Appendices A and B for monitoring methods.

Duckworth, S. (1976), California Air Resources Board, personal communication. Provided letter from Gregory Sharp of the Exposure Assessment Branch, Population Studies Division, U.S. Environmental Protection Agency, which outlined the range of variation in CHESS sampling schedules.

Evans, G.F., "Precision of LACS Sampling and Analytical Methods," in The Los Angeles Catalyst Study Symposium, Research Triangle Park, North Carolina, Environmental Monitoring and Support Laboratory, Office of Research and Development, U.S. Environmental Protection Agency Publication EPA-600/4-77-034.

Heiderscheit, L.T., and M.B. Hertz (1977), An Assessment of the CHESS Sulfate and Nitrate Data During the Period RETA Performed the Chemical Analysis, Research Triangle Park, North Carolina, Health Effects Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency Publication EPA-600/1-77-004.

Lee, R.E. Jr., and J. Wagman (1966), "A Sampling Anomaly in the Determination of Atmospheric Sulfate Concentration," American Industrial Hygiene Assoc. J., Vol. 27, No. 3.

Porter, M. et al. (1976), "Statistical Comparison of Manual and Automated Methods for Analysis of Sulfate and Nitrate in Particulate Matter," Southern California Air Pollution Control District, Metropolitan Zone, a Technical Services Division Report, June 1976.

Thomas, M.D., J.O. Ivie and T.C. Fitt (1946), "Automatic Apparatus for Determination of Small Concentrations of Sulfur Dioxide in Air," Ind. Engr. Chem., Anal. Ed., Vol. 18, pp. 383-87.

U.S. Public Health Service (1962), "Air Pollution Measurements of the National Air Sampling Network", U.S. Department of Health, Education and Welfare, Public Health Service Publication No. 978.

Wadley, M.W., and R.D. MacPhee (1976), "Measurements of Suspended Particulate Matter in the Atmosphere of Los Angeles County, 1965-1974, A Ten-Year Summary," Southern California Air Pollution Control District, Metropolitan Zone, Air Quality Report No. 82.

Welch, A.F., and J.P. Terry (1960), "Developments in the Measurement of Atmospheric Sulfur Dioxide," J. Amer. Ind. Hygiene Assoc. Vol. 21, p. 316.

West, P.W., and G.C. Gaeke (1956), "Fixation of Sulfur Dioxide as Sulfilomercurate III and Subsequent Colorimetric Determination," Anal. Chem., Vol 28, pp. 1816-1819.

# APPENDIX B2

# DATA ACQUISITION AND PREPARATION

## B2.1 The Los Angeles Air Pollution Control District (LAAPCD) Data Base

Data on suspended sulfate and sulfur dioxide concentrations were hand copied from the files of the LAAPCD. The period covered was August 1965 through December 1974. If duplicate sulfate samples were available for a 24-hour period, then the arithmetic mean of the two observations was recorded. The LAAPCD's daily average sulfur dioxide values were recorded in parts per million for days on which sulfate samples were scheduled. Sulfur dioxide concentrations were subsequently translated to micrograms per cubic meter using the Federal Register reference method calibration conditions of one atmosphere pressure and a temperature of 25°C.

## B2.2 The Community Health Environmental Surveillance System (CHESS) Data Base

Xerox copies of computer generated listings of the CHESS data were obtained from the files of the California Air Resources Board. The period covered was 1972 through 1974. Data on suspended particulate sulfates and sulfur dioxide were transcribed into three separate files: sulfates, 35 ml $SO_2$ samples, and 50 ml $SO_2$ samples. The two separate sulfur dioxide data bases overlap for a few days at the end of 1973. For the purposes of the computations in this report, the 35 ml $SO_2$ samples were used exclusively during calendar years 1972 and 1973, while 50 ml $SO_2$ samples were used in calendar year 1974.

As noted in Appendix B1, some of the raw CHESS sulfate data taken from September 1972 through early June 1974 were labeled by CHESS as follows:

> The sulfate data listed on this page must be multiplied by a factor of 1.51 to correct for an analysis error. The factor was determined by reanalysis of a substantial subset of the affected data.

This correction was incorporated into the data base on the days indicated by CHESS.

Since the CHESS 24-hour sampling period nominally began at 11:00 a.m. daily, CHESS data can not be attributed entirely to a single calendar day. For the purposes of this analysis, the CHESS program's convention of assigning the sample's stop date to each data point was adopted. On occasion, the available xerox copies of the CHESS data were difficult to read, and a few minor errors in data transcription may have occurred.

### B2.3 The National Air Surveillance Network (NASN) Data Base

Xerox copies of the NASN suspended particulate sulfate data for the years 1972 through 1974 were furnished by the California Air Resources Board. Copies of NASN sulfur dioxide data for the same years were obtained on punch cards in SAROAD format from the U.S. Environmental Protection Agency. All data for all stations in the South Coast Air Basin were requested. No sulfate data were received for Riverside in the years 1973 and 1974. No sulfur dioxide data were available for Burbank, Ontario and Riverside.

# APPENDIX B3

## FREQUENCY OF OCCURRENCE OF SULFATE CONCENTRATIONS 1972 THROUGH 1974

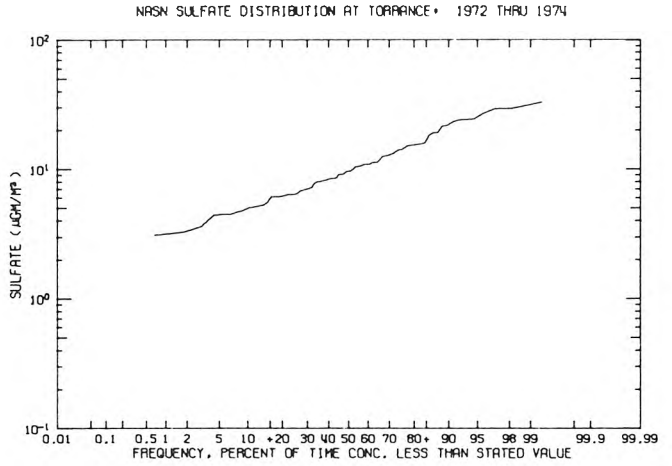



FIGURE B3.1

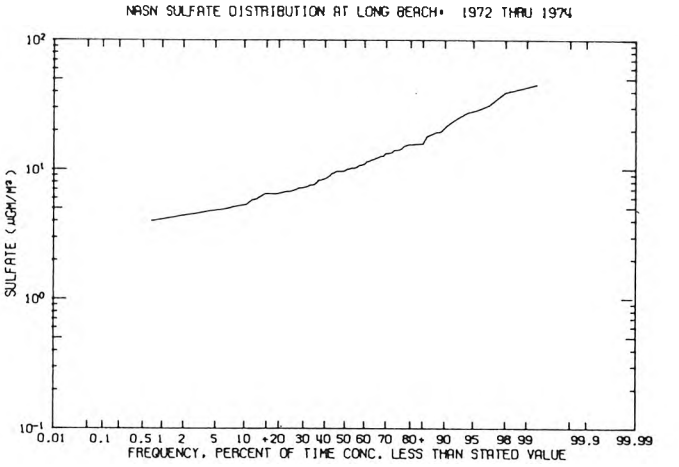



FIGURE B3.2

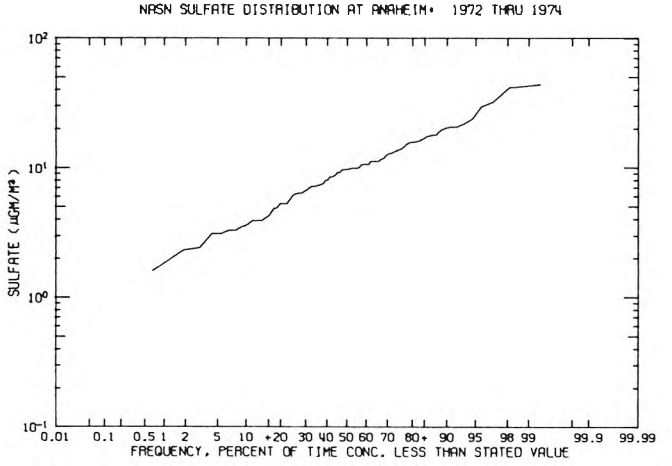



FIGURE B3.3

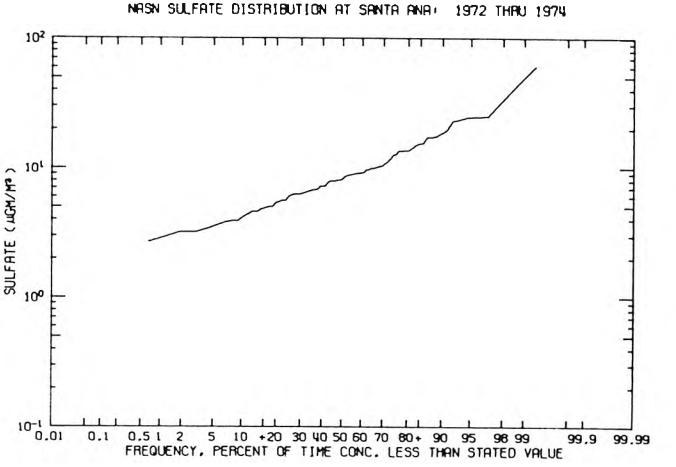



FIGURE B3.4

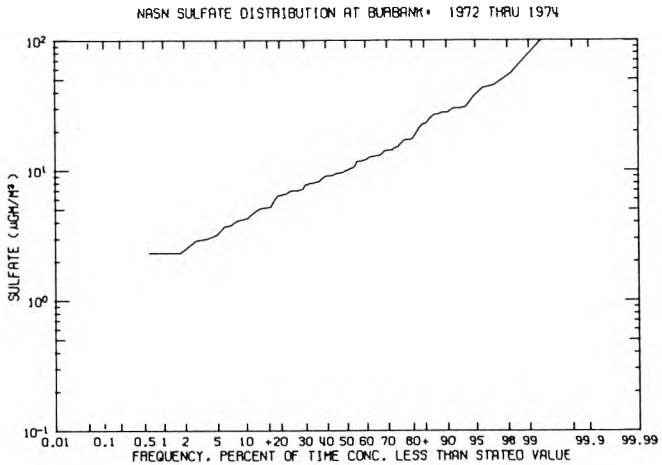



FIGURE B3.5

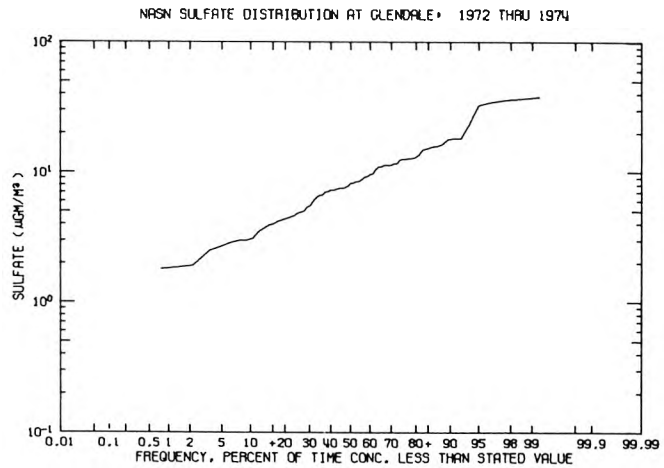



FIGURE B3.6

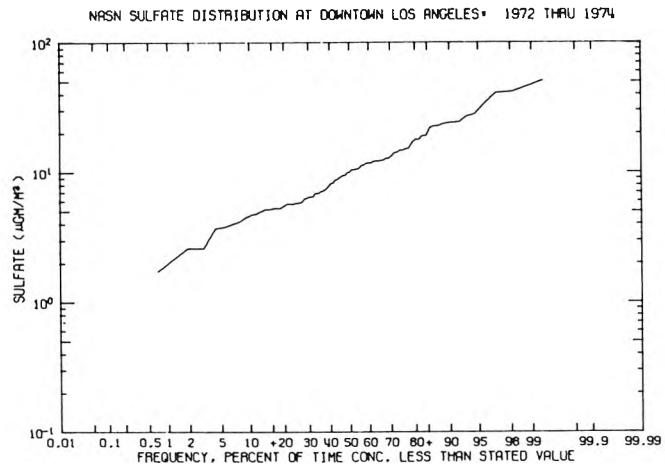



FIGURE B3.7

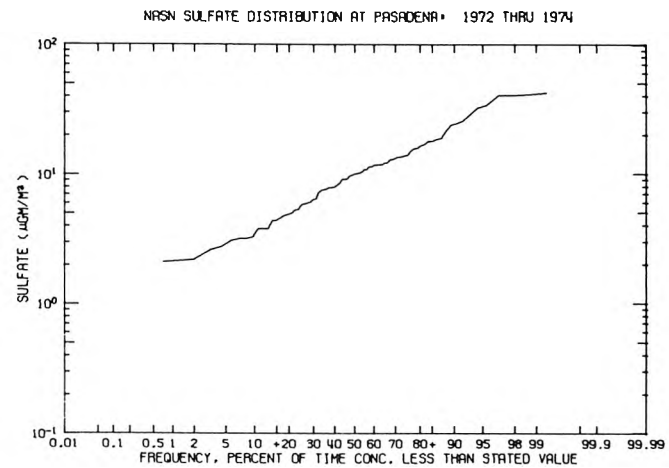



FIGURE B3.8

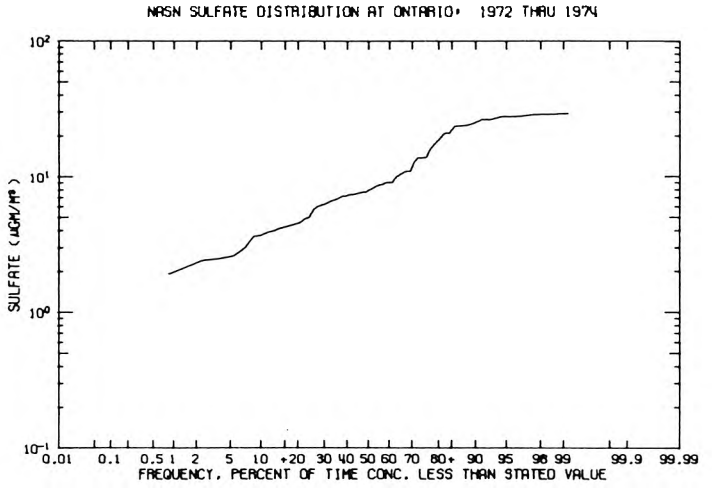



FIGURE B3.9

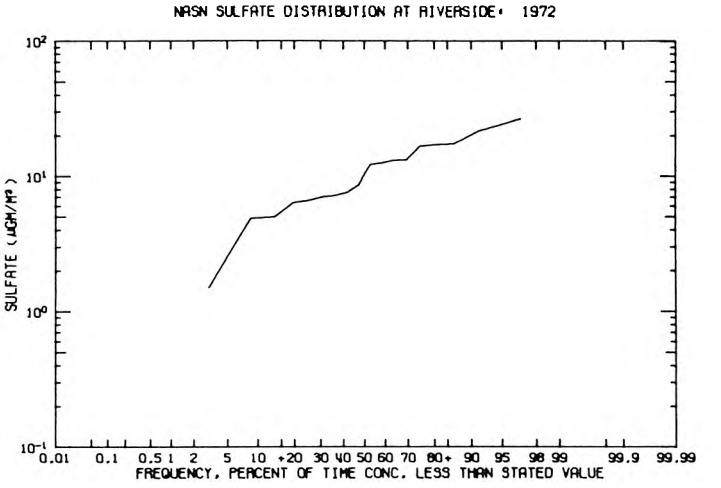



FIGURE B3.10

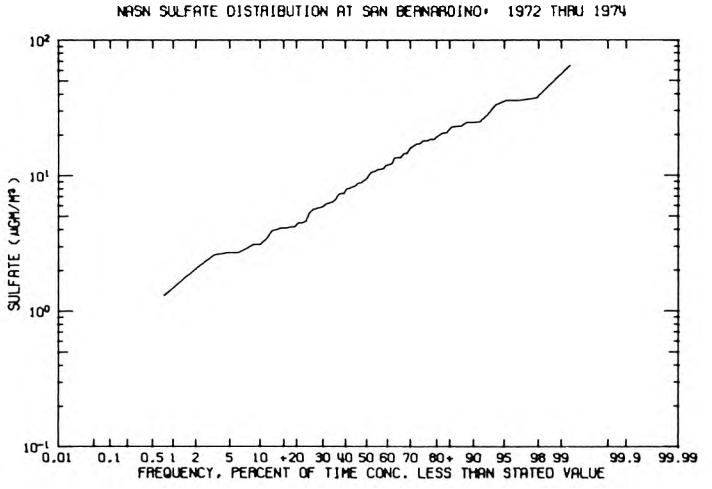



FIGURE B3.11

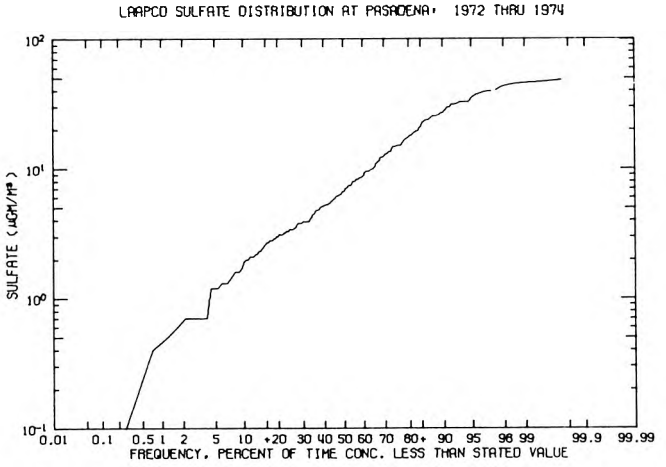
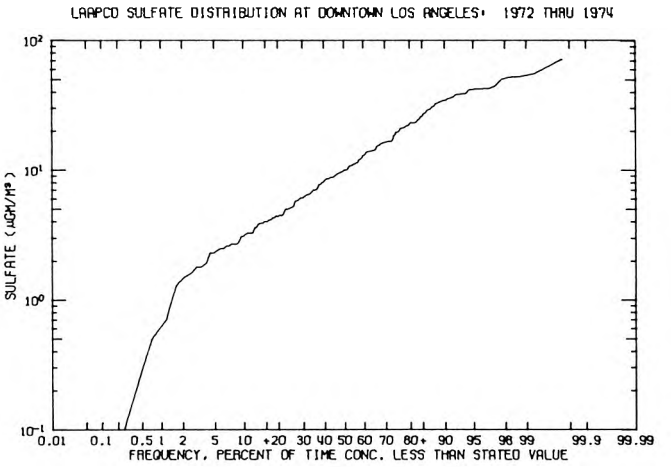



FIGURE B3.12

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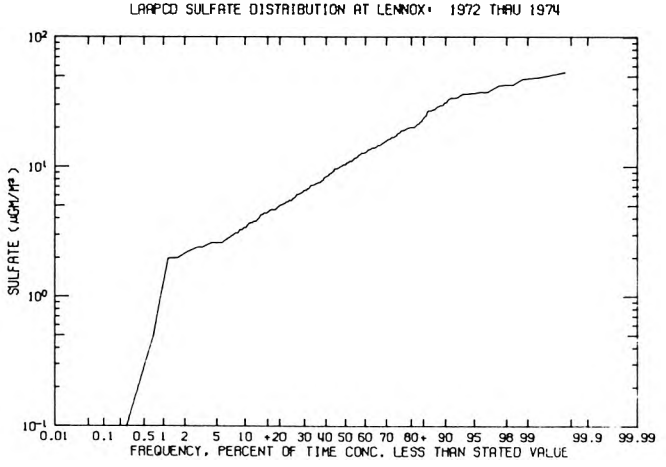
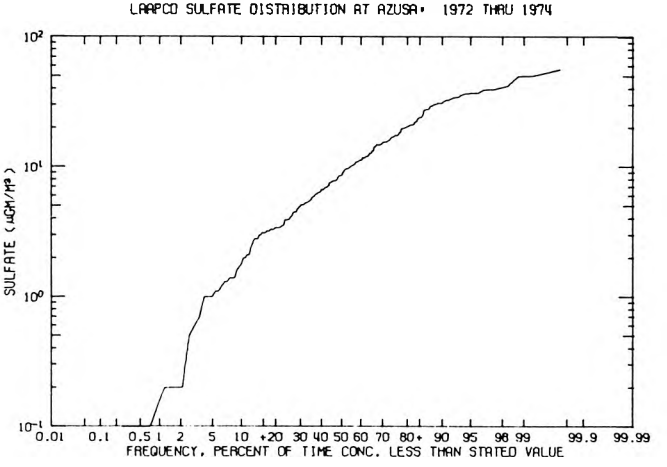



FIGURE B3.14

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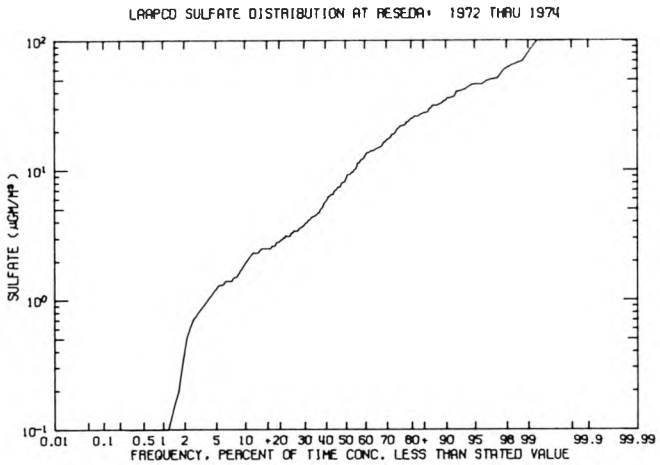
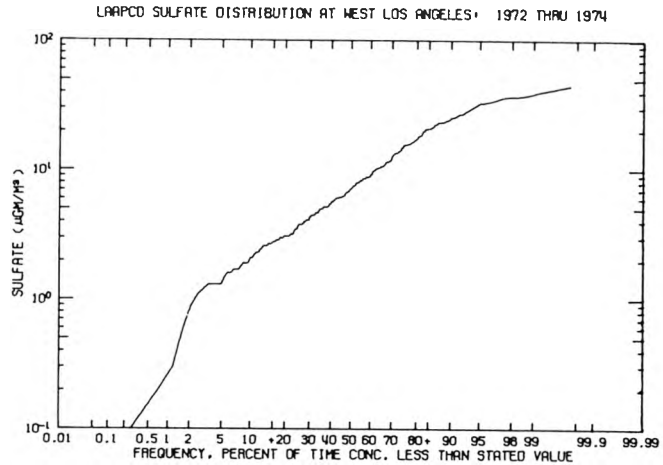



FIGURE B3.16

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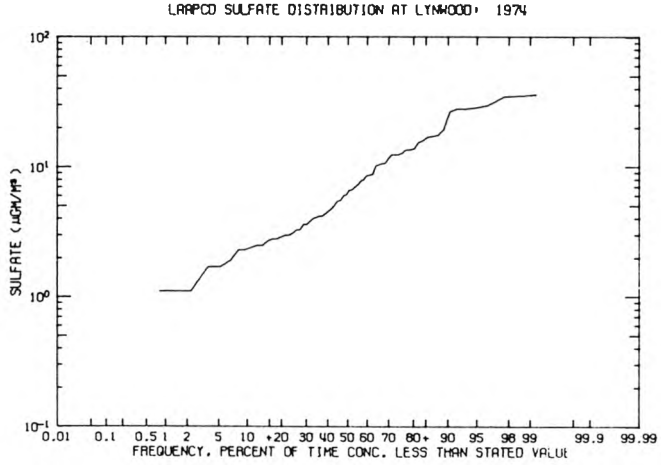



FIGURE B3.18

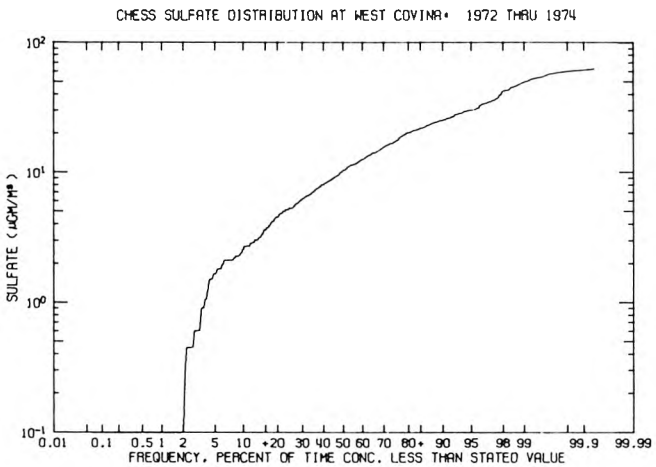



FIGURE B3.19

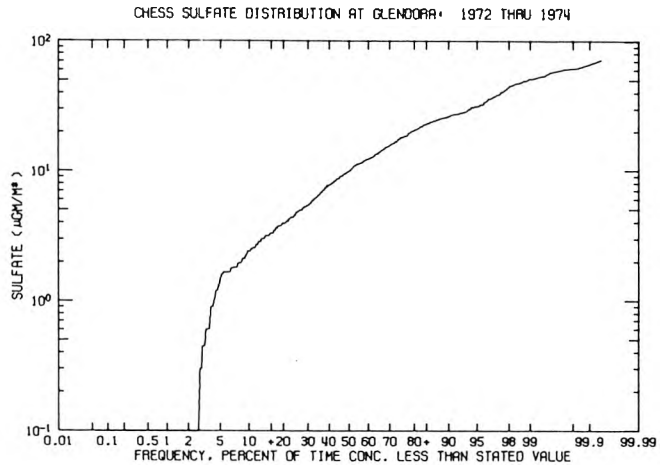



FIGURE B3.20

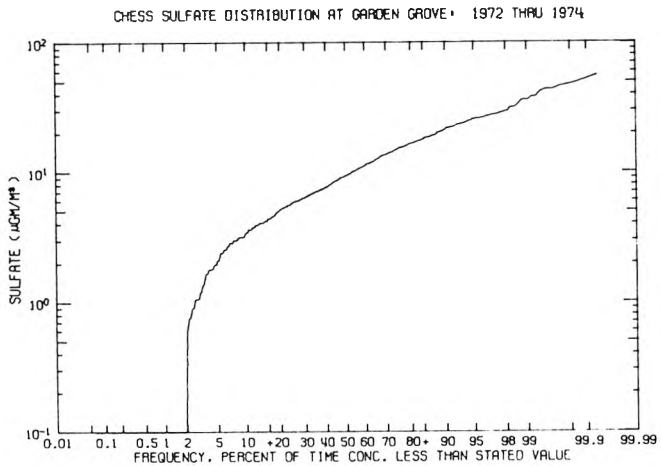



FIGURE B3.21

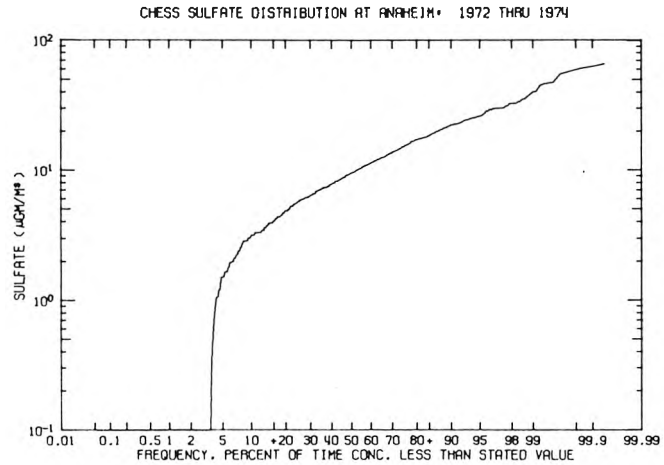



FIGURE B3.22

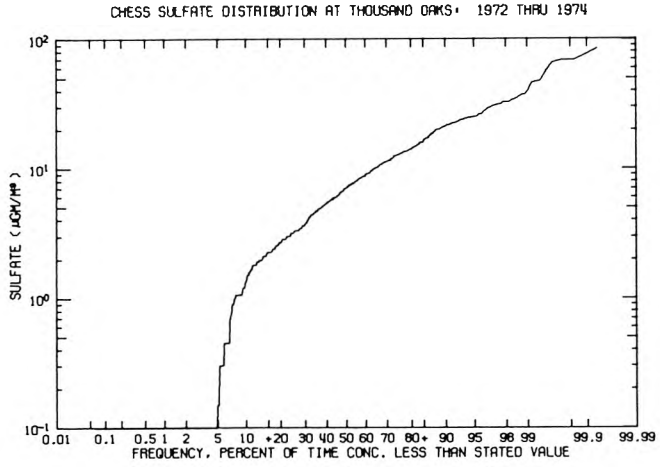



FIGURE B3.23

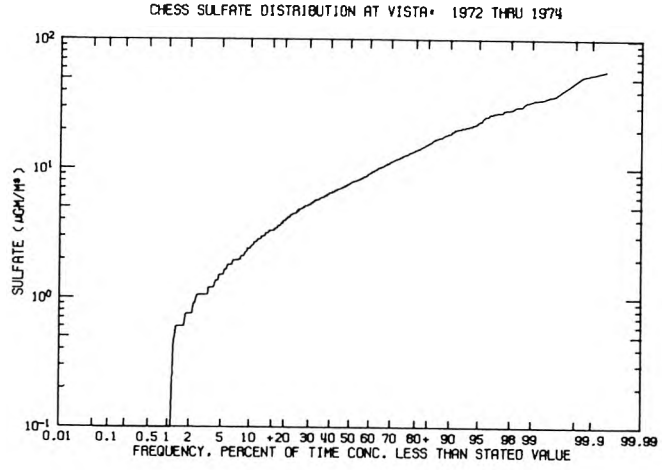



FIGURE B3.24

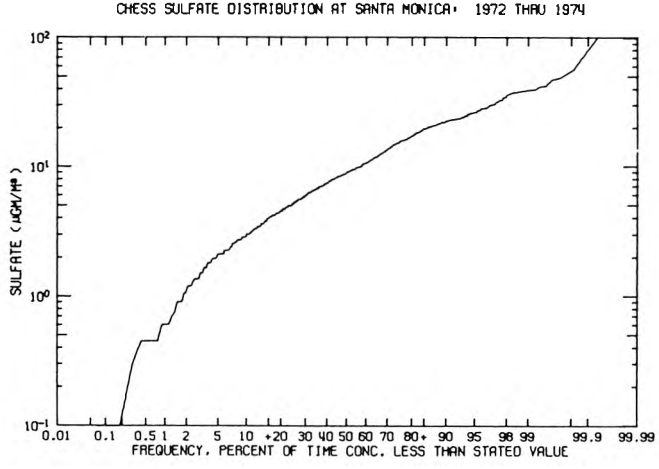



FIGURE B3.25

# APPENDIX B4

## PARAMETER ESTIMATION PROCEDURES FOR SULFATE AIR QUALITY DATA

Empirical work pioneered by Larsen (1971) suggests that air quality measurements approximately follow a simple two parameter log-normal distribution for all pollutants and all averaging times. Graphs presented in Appendix B3 generally confirm that rule of thumb at sulfate concentrations above 2 $\mu gm/m^3$. As described in the body of this report, departure from a two parameter log-normal distribution at low concentrations may well be due to minimum detection limit problems arising from the sulfate measurement techniques employed.

Let us establish some nomenclature with which to define the parameters of the log-normally distributed air quality data. Assume that the record at an air monitoring station consists of n stochastically independent observations $y_1, y_2, y_3, \ldots, y_n$. The sample arithmetic mean of this data will be referred to as $\bar{y}$, and the sample variance as $s^2$. The true underlying arithmetic mean of the distribution from which these samples were drawn will be called $\mu$, and the true underlying variance is called $\sigma^2$.

The natural log of each sample value $y_i$ will be referred to as $x_i$. The x's are thus a normally distributed population obtained by direct transformation of the sulfate air quality observations. The sample mean of the x's will be called $\bar{x}$. The true underlying mean of the population from which the x's are drawn will be called $\alpha$, and the true underlying variance of the x's will be called $\beta^2$.

The geometric mean, $\mu_g$, and geometric standard deviation, $\sigma_g$, of the raw sulfate observations may be estimated from $\alpha$ and $\beta^2$ as follows:

$$\mu_g = e^{\alpha} \tag{B4.1}$$

$$\sigma_g = e^{\beta} \tag{B4.2}$$

These geometric statistics are often used to describe air quality measurements because long-run changes in pollutant emissions in an air basin are usually expected to affect the geometric mean air quality level while leaving the geometric standard deviation largely unchanged.

One useful relationship between the parameters of the distributions of the x's and y's is that

$$\mu = e^{\alpha + \frac{1}{2}\beta^2} \tag{B4.3}$$

This means that given good estimates of $\alpha$ and $\beta^2$, one can make an efficient estimate of the arithmetic mean, $\mu$, of a group of sulfate air quality data. Since it is the arithmetic mean, $\mu$, which our future air quality model will calculate, that is an important expression.

We wish to estimate the parameters $\alpha$ and $\beta^2$ of a set of air quality data. Ordinarily, $\alpha$ and $\beta^2$ would be obtained easily by taking the moments of the transformed sulfate samples. But the existence of possibly bad data in the LAAPCD and CHESS data bases at sulfate concentrations below 2 $\mu gm/m^3$ causes us to seek a method by which the existence of those low-valued samples may be acknowledged without explicitly

using the numerical values obtained. In short, we advise censoring the sulfate routine air monitoring data bases below 2 $\mu gm/m^3$. [1]

An analytical approach to estimating the parameters of a censored normal distribution is given by Hald (1952). For the large number of calculations which we have to perform, that procedure is simply too complicated to yield to rapid automation. A variation of the alternate "graphical" method for estimating the parameters of a log-normal distribution was used instead.

In the graphical method, the parameters $\alpha$ and $\beta$ are estimated from the 50th percentile point and slope, respectively, of the sulfate data when graphed on log-probability paper. In order to plot such a graph, the data are rank ordered and each data point is assigned a probability of occurrence on a normal probability scale. The plotting position for a given data point is obtained from a formula which is usually of the form

$$p = \frac{r-a}{n+(1-2a)} \qquad \text{(B4.4)}$$

where

r = rank of that data point
p = probability at which the $r^{th}$ ranked point is plotted
n = total number of samples considered
a = a parameter between zero and one selected on the basis of the purpose for which the exercise is being undertaken

---

[1] The background data of Hidy, et al., (1974) will not be censored because there are too few data points to tell what the lower tail of their distribution looks like.

A wide variety of recommended values of the parameter "a" exist in the literature. Koh (1977) has shown that any choice of "a" between zero and one can be defended on theoretical grounds. For small sample populations drawn at random from a large normal distribution with known mean and variance, Koh found empirically that a value of a = 0.44 was best suited to re-extracting the original sample variance from a least squares fit to the slope of the data points on probability paper after having regressed sample values on plotting position. That value of a = 0.44 has been used throughout this study, along with Koh's computer software which insures maintenance of the empiricism involved in selecting the value of "a" that was used.

In order to automate this "graphical" procedure, the data are rank ordered and plotting positions are calculated for each point in a set of sulfate samples. The plotting positions are next expressed in units of standard deviations above and below the median of a standard normal (0,1) distribution centered on the 50th percentile point. The natural log of each sulfate sample is taken. Then sulfate samples below 2 $\mu gm/m^3$ were censored from the lower tail of the cumulative probability distribution, while retaining the plotting position for all higher valued samples as if the lower tail were still present. A regression line is next fitted to the rank ordered data by regressing the logs of the sulfate concentrations on plotting position (in standard deviations from the 50th percentile). All of the above calculations are done on an IBM 370/158 computer rather than by actually graphing the data.

Variance estimates were obtained from the square of the slope, b, of this regression line. Since N = 1096 consecutive 24-hour samples at a monitoring station would exhaust the entire set of possible days during our three year period (or 31 days within a monthly sample), we are clearly sampling from a finite population of days, and an unbiased estimate of $\beta^2$ would be obtained as (reference Hald, 1952)

$$\beta^2 = \frac{N-1}{N} (b)^2 \qquad \text{(B4.5)}$$

In a similar fashion, $\alpha$ is estimated by the zero standard deviation intercept (50th percentile point) of our regression line fitted to the censored cumulative probability distributions.

As a check on the log-normality assumptions and procedure used in estimating $\alpha$ and $\beta^2$, we can estimate the theoretical arithmetic mean, $\mu$, for a sample population from equation (B4.3). In Tables 2.3, 2.7, 2.8, and 2.9 in the main body of this research report, that computed value of $\mu$ is compared to sample arithmetic mean, $\bar{y}$. The comparison is very close in all cases. An even more stringent test of this parameter estimation procedure is provided by the small sample monthly estimates of $\bar{y}$ and $\mu$ given by the o's and +'s, respectively in the figures at the end of this appendix. Even for the LAAPCD data which average only 6 samples per month, the monthly estimates of $\bar{y}$ and $\mu$ are still quite close.

Next we wish to calculate a 95% confidence interval about the arithmetic mean of the sulfate data at each air monitoring station. Those confidence intervals are needed if air quality model calculations

are to be compared to observed sulfate concentration measurements. The literature on estimating confidence intervals about the arithmetic mean of log-normally distributed data is not very helpful, particularly for small sample estimation problems. Koch and Link (1970) have surveyed methods in current use for establishing confidence intervals on the arithmetic mean of log-normally distributed data. They located five methods for performing the calculations, and after applying each method to the same data base, they obtained upper confidence limit estimates on their arithmetic mean which ranged over a full order of magnitude from one method to the next. A well agreed upon formula for performing these calculations is not apparent.

In their well known monograph on the properties of log-normal distributions, Aitchison and Brown (1957) state that theory provides no means of obtaining exact confidence intervals for the arithmetic mean and arithmetic standard deviation of log-normally distributed data. Invoking the central limit theorem, about all that can be said is that sample arithmetic mean and sample arithmetic standard deviation are asymptotically normal with means $\mu$ and $\sigma$, respectively. Therefore they state that a large sample confidence interval for $\mu$ may be constructed as

$$\bar{y} - N_{P_1}\sqrt{V\{\bar{y}\}} < \mu < \bar{y} - N_{P_2}\sqrt{V\{\bar{y}\}} \qquad \text{(B4.6)}$$

Where

$V\{\bar{y}\}$ is the variance of the sample mean

$N_{P_1}$, $N_{P_2}$ are appropriate percentile points at the upper and lower tails, respectively, of the normal (0,1) distribution

In our case, expression B4.6 will have to serve as a small sample confidence interval as well.

At least two sources of uncertainty contribute to the variance of $\bar{y}$. The first of these is due to infrequent sampling, particularly at the LAAPCD and NASN monitoring sites. When only a few days are chosen to be sampled from within a month or a year, the mean value of those sulfate concentration measurements is an uncertain estimate of the true population mean. That is because atmospheric concentrations fluctuate from day to day and the entire population was not observed. Secondly, there is an uncertainty introduced into any monitoring program by the accuracy of the measurement technique employed, even if all days of the month or year were sampled.

The problem of attributing components of the variance of $\bar{y}$ to atmospheric fluctuations and to measurement errors will be based on a model of two stage sampling. The first stage consists of drawing a random sample of $n_1$ primary units (days) from a group of $N_1$ possible cases (the total number of days of a month or year). The second stage of the sampling process is to choose $n_2$ measured values from amongst the $N_2$ results which could have been delivered by a large number of simultaneous attempts to measure that day's atmospheric sulfate concentration by a somewhat inaccurate method. Each observation chosen thus can be thought of as differing from the mean sulfate value due to two fluctuating components

$$y_{i\zeta} = \mu + w_i + z_{i\zeta} \qquad \text{(B4.7)}$$

where $w_i$ denotes the contribution to the departure from the mean due to fluctuations in atmospheric concentration from day to day

and $z_{i\zeta}$ denotes the contribution to the departure from the mean due to the measurement technique employed.

For a finite population of $N_1$ possible days to be sampled and $N_2$ potential samples per day, with experimental values $y_{i\zeta}$, $i = 1,2,...N_1$, and $\zeta = 1,2,...N_2$ we obtain (Hald, 1952)

$$\sigma^2 = \frac{1}{N_1 N_2} \sum_{i=1}^{N_1} \sum_{\zeta=1}^{N_2} (y_{i\zeta} - \mu)^2 \tag{B4.8}$$

$$\sigma^2 = \frac{1}{N_1} \sum_{i=1}^{N_1} (\mu_i - \mu)^2 + \frac{1}{N_1 N_2} \sum_{i=1}^{N_1} \sum_{\zeta=1}^{N_2} (y_{i\zeta} - \mu_i)^2 \tag{B4.9}$$

$$\sigma^2 = \sigma_1^2 + \sigma_2^2 \tag{B4.10}$$

Where

$$\mu_i = \frac{\sum_{\zeta=1}^{N_2} y_{i\zeta}}{N_2} \tag{B4.11}$$

$$\mu = \frac{\sum_{i=1}^{N_1} \sum_{\zeta=1}^{N_2} y_{i\zeta}}{N_1 \quad N_2} \tag{B4.12}$$

If a random sample of $n_1$ days are chosen from amongst the $N_1$ possible days, then the variance of the mean of the $w_i$ is given by:

$$V\{\bar{w}\} = \frac{\sigma_1^2}{n_1} \left( 1 - \frac{n_1 - 1}{N_1 - 1} \right) \tag{B4.13}$$

The latter term on the right hand side of expression (B4.13) is a finite population correction (e.g., if all days of the month are sampled, $n_1 = N_1$, and there is no uncertainty introduced into the monthly mean from having missed sampling a possible event).

For each day sampled, i, we choose $n_2$ of the experimental results from among the possibly infinite number of samples which could have been measured by simultaneous execution of our sampling protocol. Within each of these days, the variance of the mean of the experimental results is

$$V\{\bar{z}_i\} = \frac{\sigma_{2i}^2}{n_2} \qquad \text{(B4.14)}$$

Where $\sigma_{2i}^2$ is the variance in the underlying measurement technique applied within the context of day i.

Combining these two sources of variation, we get

$$V\{\bar{y}\} = \frac{\sigma_1^2}{n_1}\left(1 - \frac{n_1 - 1}{N_1 - 1}\right) + \frac{\sigma_2^2}{n_1 n_2} \qquad \text{(B4.15)}$$

where $\sigma_2^2$ is the mean of all $\sigma_{2i}^2$'s.

For the case of a single measured value per day sampled, $n_2 = 1$, and

$$V\{\bar{y}\} = \frac{\sigma_1^2}{n_1}\left(1 - \frac{n_1 - 1}{N_1 - 1}\right) + \frac{\sigma_2^2}{n_1} \qquad \text{(B4.16)}$$

The coefficients of variation for individual sulfate measurements made by the LAAPCD, the CHESS and the NASN networks were estimated in Appendix B1. For each day i sampled we may estimate $\sigma_{2i}$ at each monitoring station by:

$$\sigma_{2i} = C\{SO_4\} \cdot \langle c(SO_4)\rangle_i \qquad \text{(B4.17)}$$

Where $C\{SO_4\}$ is the coefficient of variation of sulfate measurements made by the monitoring network of interest

$\langle c(SO_4)\rangle_i$ is the sulfate concentration measurement available for day i from that monitoring site.

Then $\sigma_2^2$ is obtained at each monitoring station by averaging over all $\sigma_{2i}^2$ at that site for the time period over which $\bar{y}$ is to be calculated.

Next, the variance $\sigma_1^2$ is estimated. Substituting the total sample variance obtained by the method of moments, $s^2 \simeq \sigma^2$, into equation B4.10, and rearranging we get:

$$\sigma_1^2 \simeq s^2 - \sigma_2^2 \qquad \text{(B4.18)}$$

Having supplied estimates for $\sigma_1$ and $\sigma_2$, the expression for $V\{\bar{y}\}$ in equation B4.18 may be inserted into equation B4.16. The 95% confidence limits estimated for the arithmetic mean of our sulfate air quality data become:

$$\mu_{lower} = \bar{y} - N_{97.5\%}\sqrt{\frac{s^2 - \sigma_2^2}{n_1}\left(1 - \frac{n_1 - 1}{N_1 - 1}\right) + \frac{\sigma_2^2}{n_1}} \qquad \text{(B4.19)}$$

$$\mu_{upper} = \bar{y} - N_{2.5\%}\sqrt{\frac{s^2 - \sigma_2^2}{n_1}\left(1 - \frac{n_1 - 1}{N_1 - 1}\right) + \frac{\sigma_2^2}{n_1}} \qquad \text{(B4.20)}$$

Confidence intervals estimated for $\mu$ at each monitoring station over each of our three years of interest are given in Tables 2.7, 2.8, and 2.9. Figures B4.1 through B4.14 show confidence intervals on $\mu$

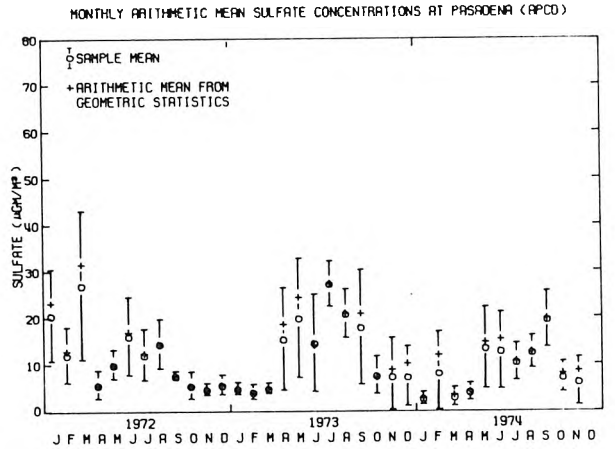



FIGURE B4.1

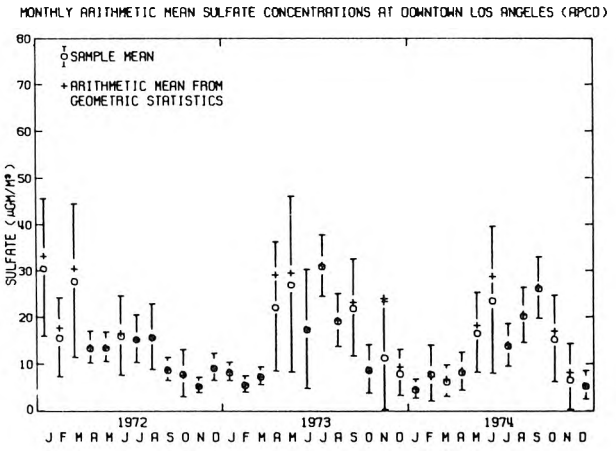



FIGURE B4.2

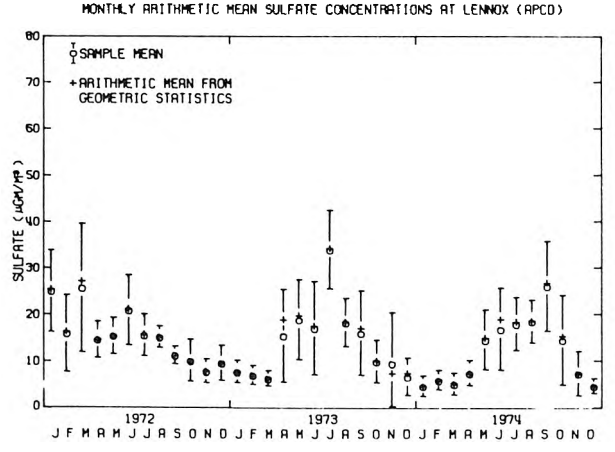



FIGURE B4.3

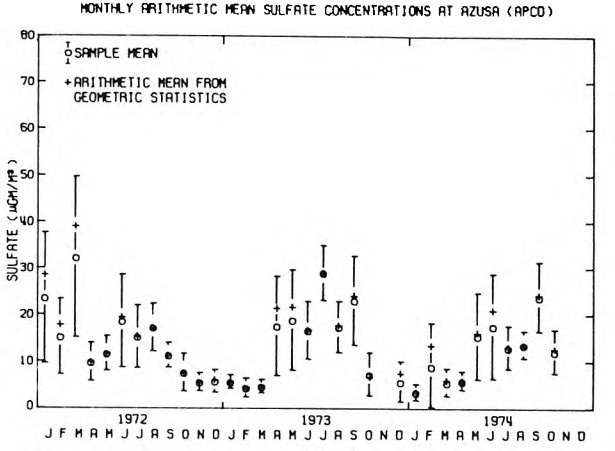



FIGURE B4.4

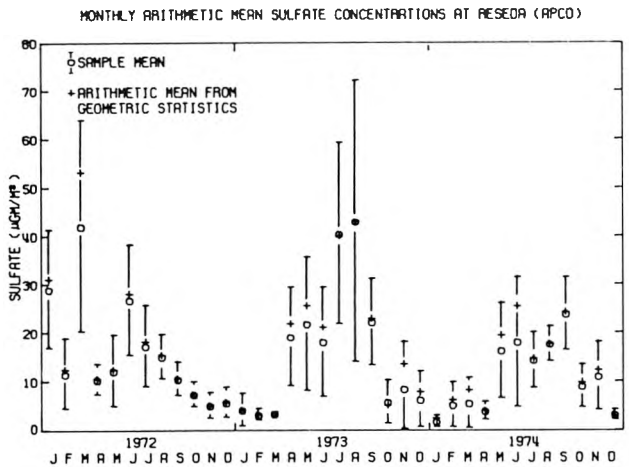



FIGURE B4.5

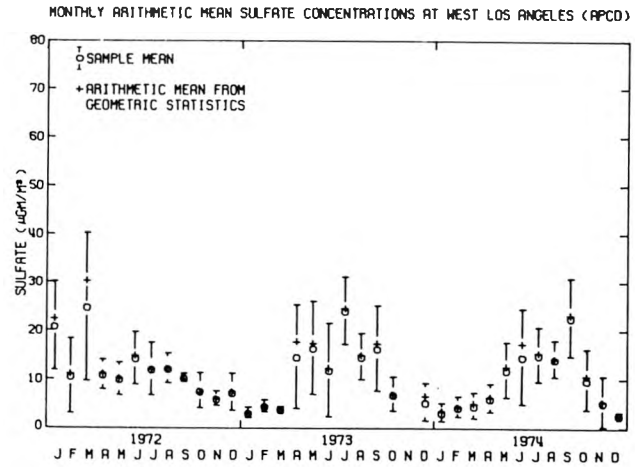



FIGURE B4.6

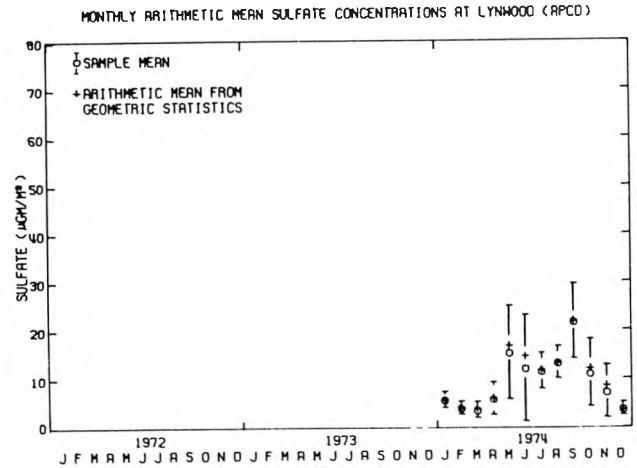



FIGURE B4.7

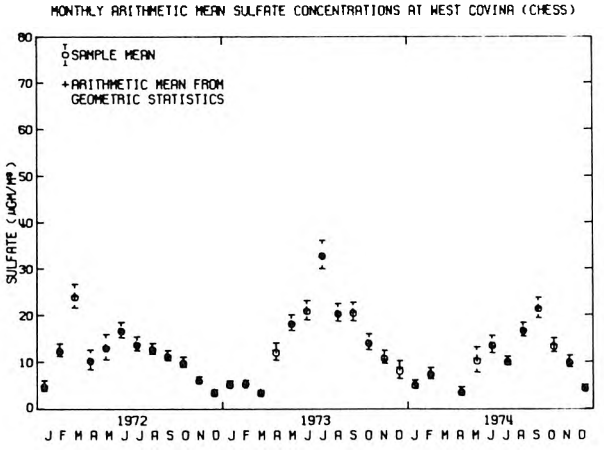



FIGURE B4.8

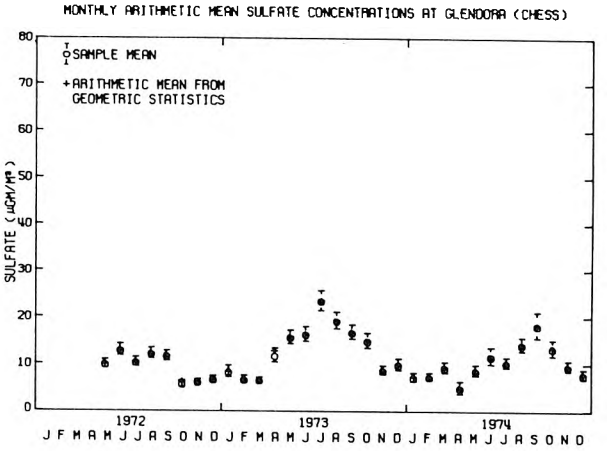



FIGURE B4.9

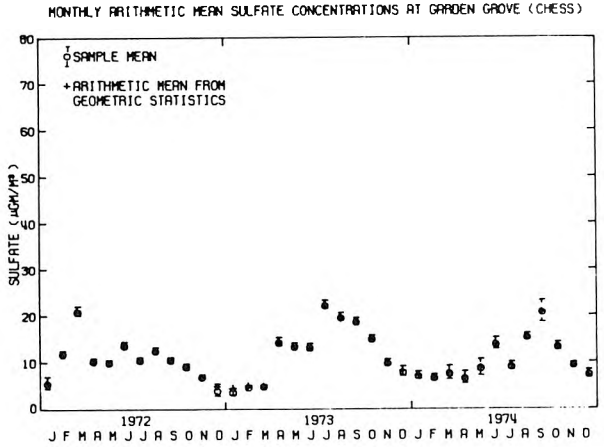



FIGURE B4.10

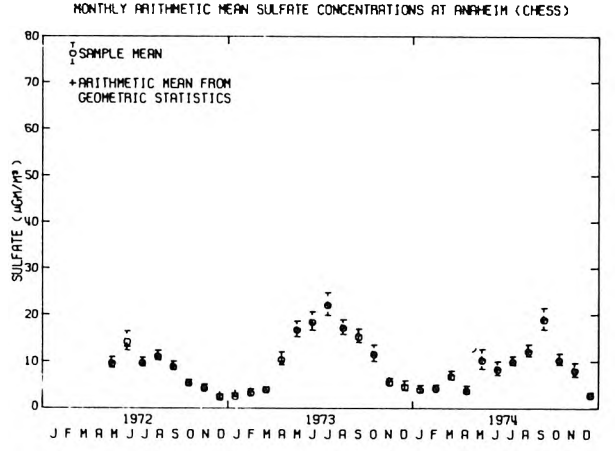



FIGURE B4.11

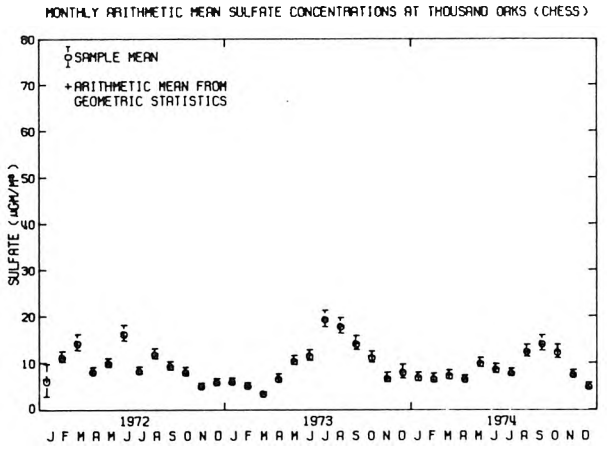



FIGURE B4.12

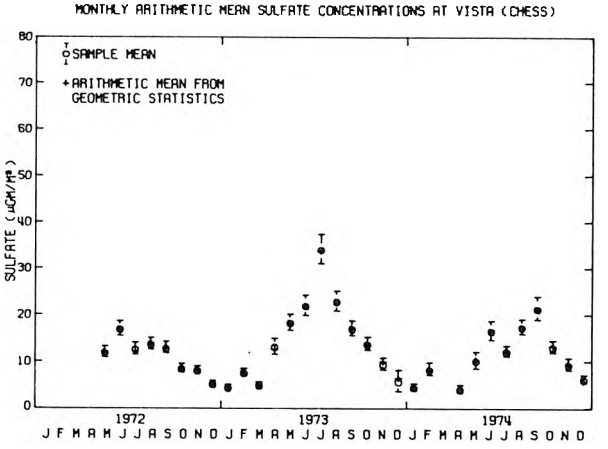



FIGURE B4.13

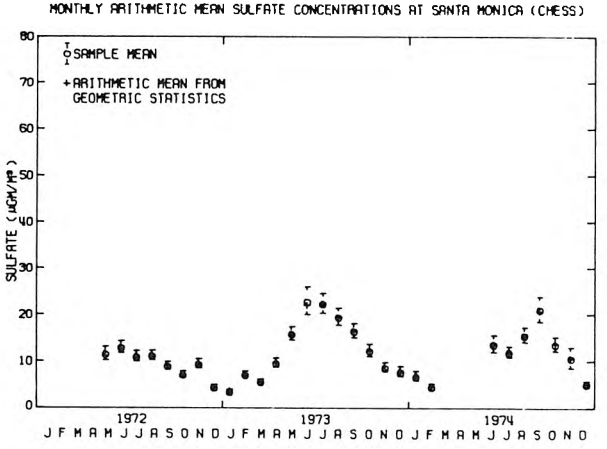



FIGURE B4.14

estimated for each month at all CHESS and LAAPCD air monitoring sites. The NASN stations are not represented because their sampling schedule is too infrequent to support monthly mean determinations.

## REFERENCES FOR APPENDIX B4

Aitchison, J., and J.A.C. Brown (1957), The Lognormal Distribution, Cambridge, Cambridge University Press.

Hald, A. (1952), Statistical Theory with Engineering Applications, New York, John Wiley and Sons.

Hidy, G.M. et al. (1974), "Observations of Aerosols over Southern California Coastal Waters," Journal of Applied Meteorology, Vol. 13, pp. 96-107.

Koch, G.S. and R.F. Link (1970), Statistical Analysis of Geological Data, New York, John Wiley and Sons, Vols. 1 and 2.

Koh, R.C.Y. (1977), "On the Question of Plotting Positions," Technical Memorandum 77-5, W.M. Keck Laboratory of Hydraulics and Water Resources, California Institute of Technology.

Larsen, R.I. (1971), A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards, Research Triangle Park, North Carolina, U.S. Environmental Protection Agency, Publication No. AP-89.

# APPENDIX B5

## SEASONAL TRENDS IN SULFATE AIR QUALITY IN THE SOUTH COAST AIR BASIN 1972-1974

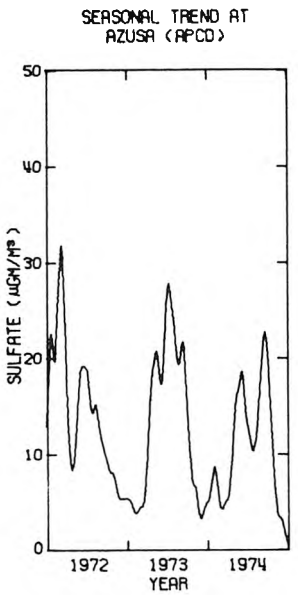



FIGURE B5.1

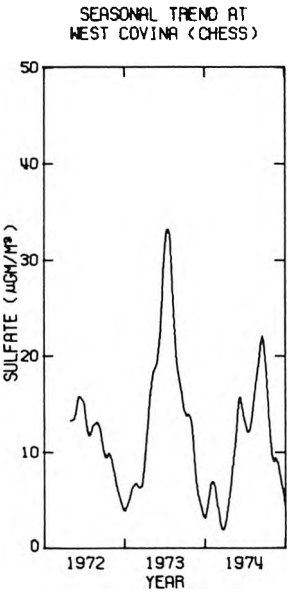



FIGURE B5.2

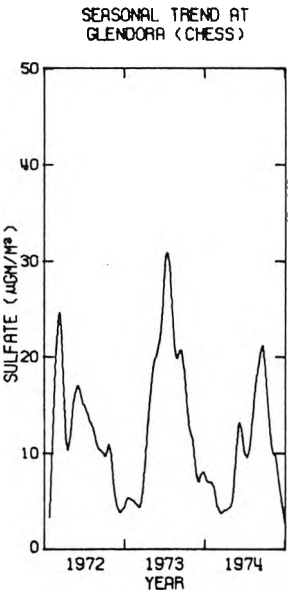



FIGURE B5.3

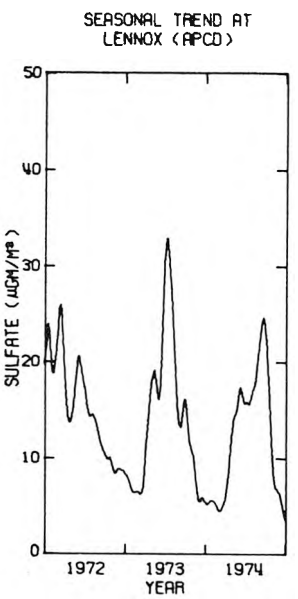



FIGURE B5.4

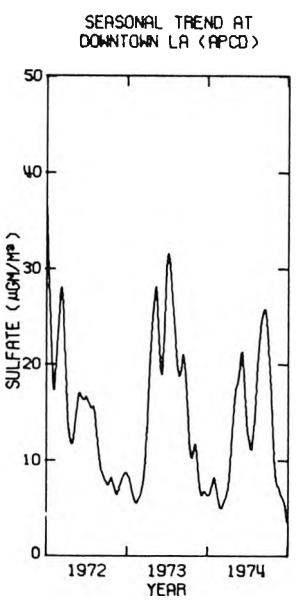



FIGURE B5.5

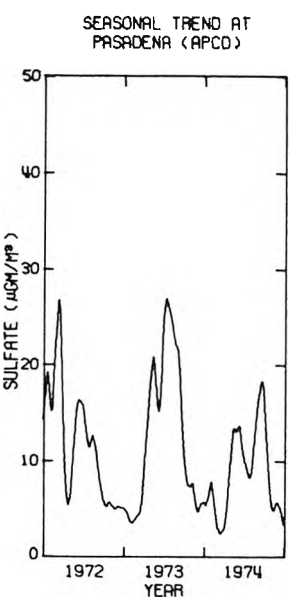



FIGURE B5.6

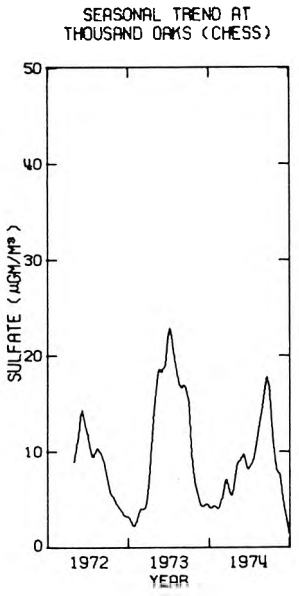



FIGURE B5.7

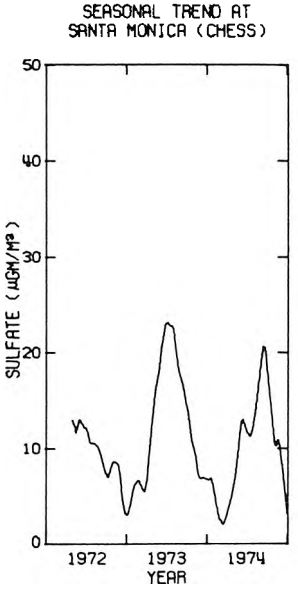



FIGURE B5.8

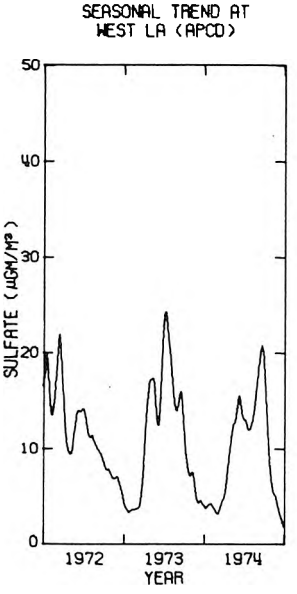



FIGURE B5.9

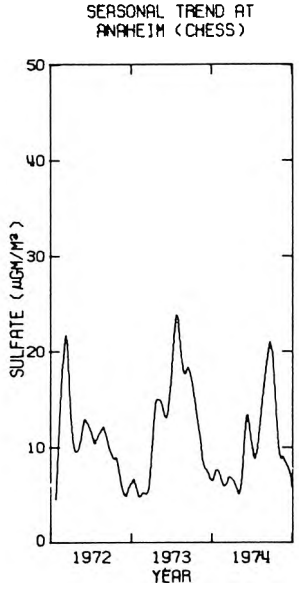



FIGURE B5.10

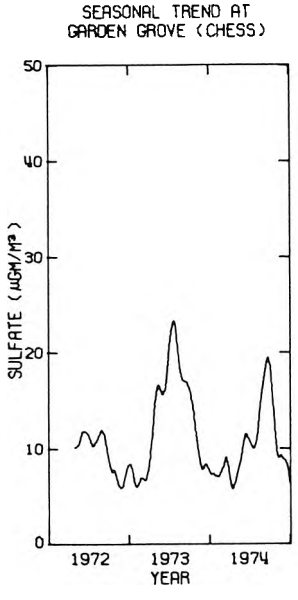



FIGURE B5.11

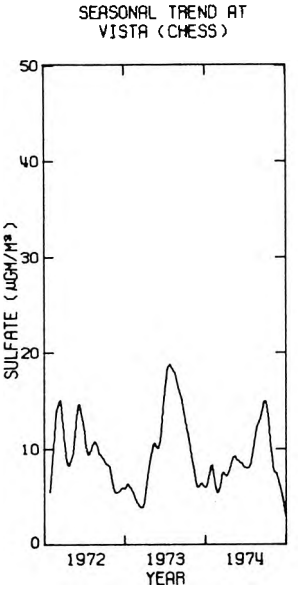



FIGURE B5.12

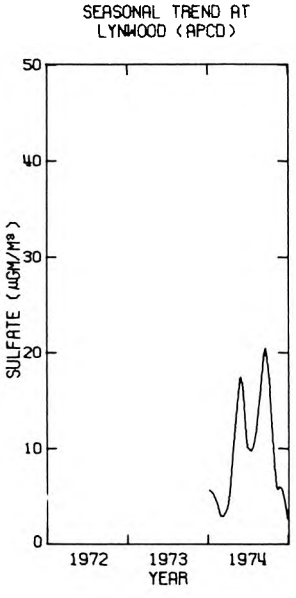



FIGURE B5.13

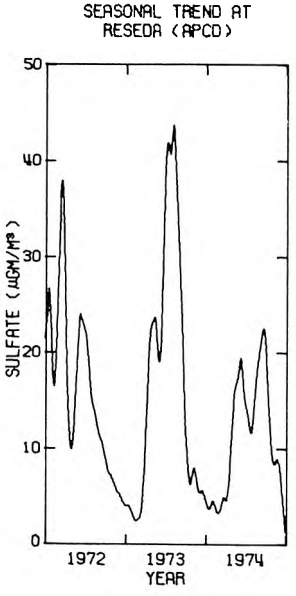



FIGURE B5.14

# APPENDIX B6

## FREQUENCY OF OCCURRENCE OF VALUES OF THE RATIO OF PARTICULATE SULFUR TO TOTAL SULFUR, $f_s$, 1972 THROUGH 1974

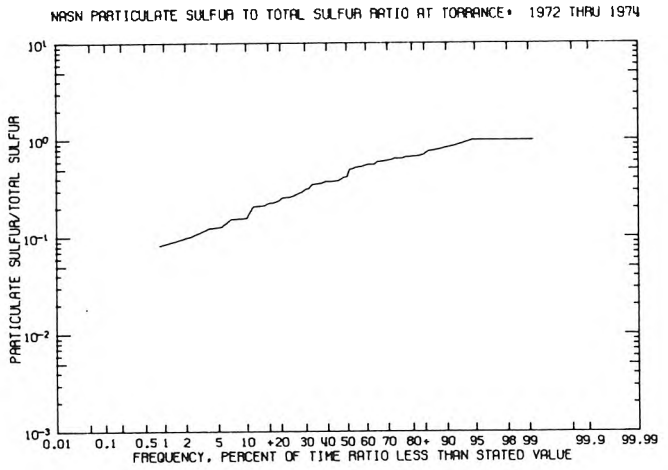



FIGURE B6.1

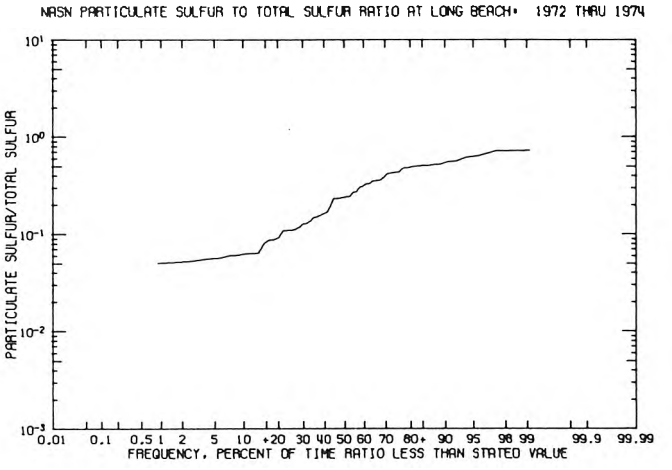



FIGURE B6.2

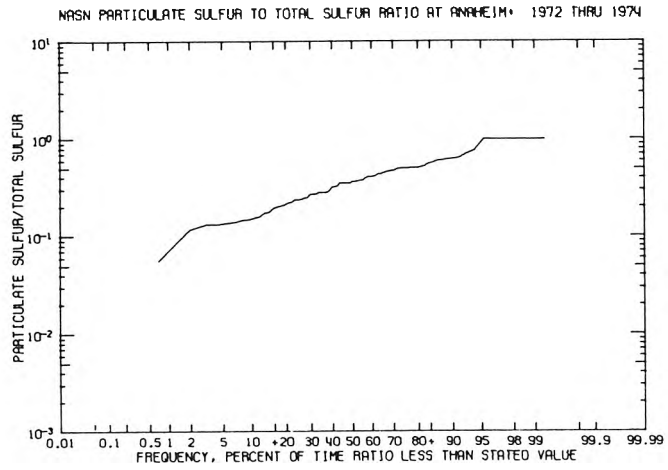



FIGURE B6.3

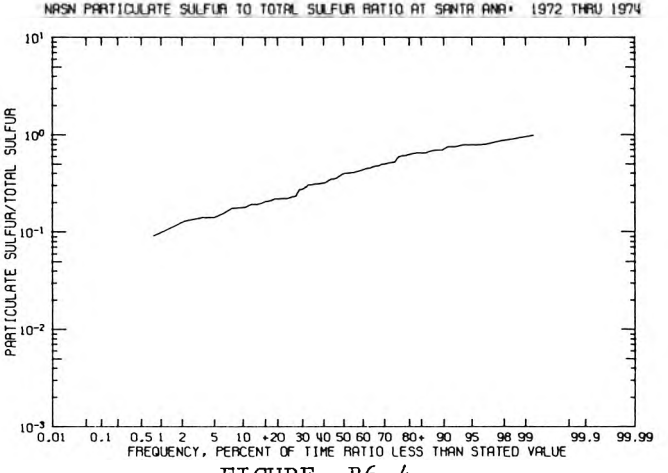



FIGURE B6.4

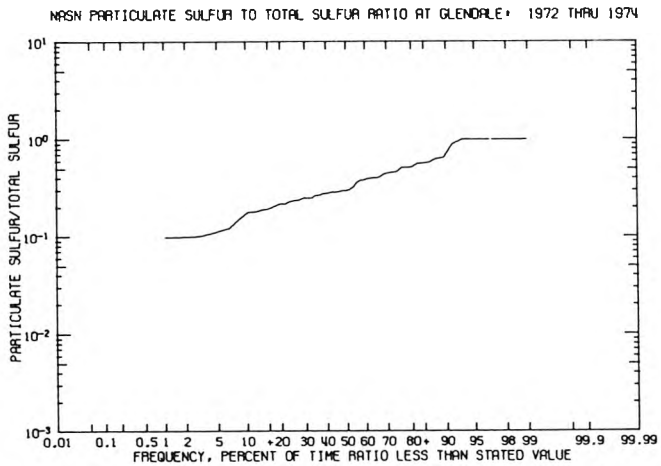



FIGURE B6.5

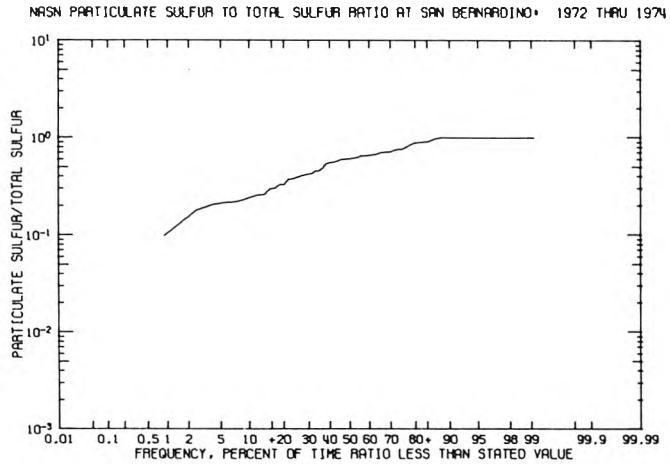



FIGURE B6.6

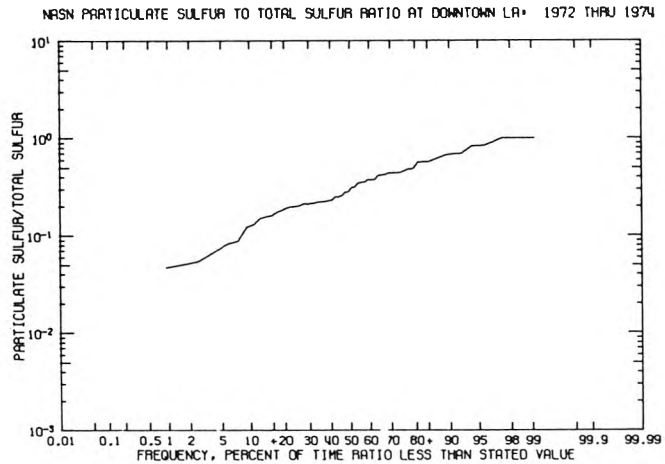



FIGURE B6.7

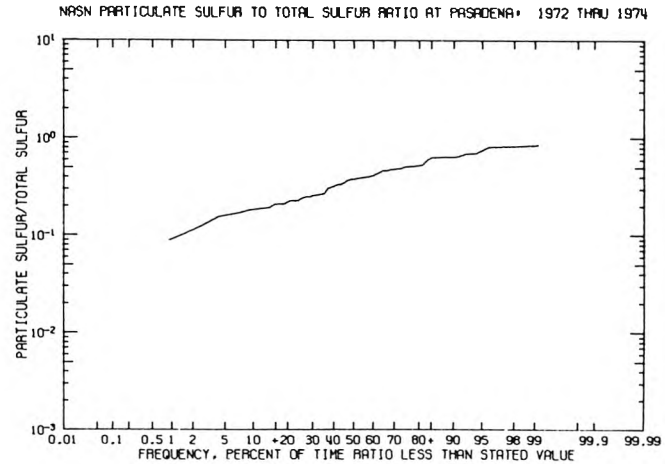



FIGURE B6.8

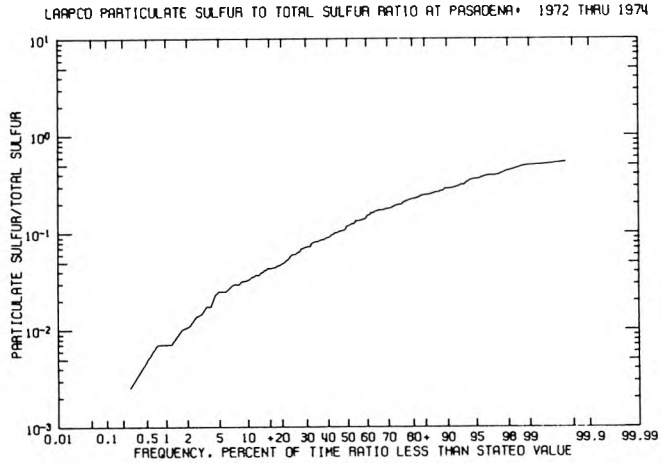



FIGURE B6.9

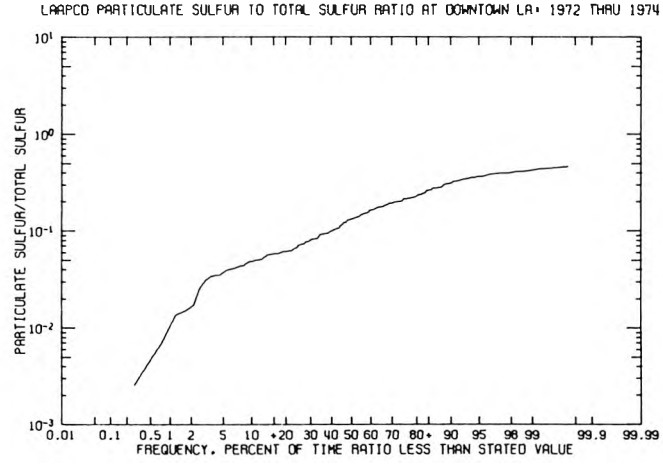



FIGURE B6.10

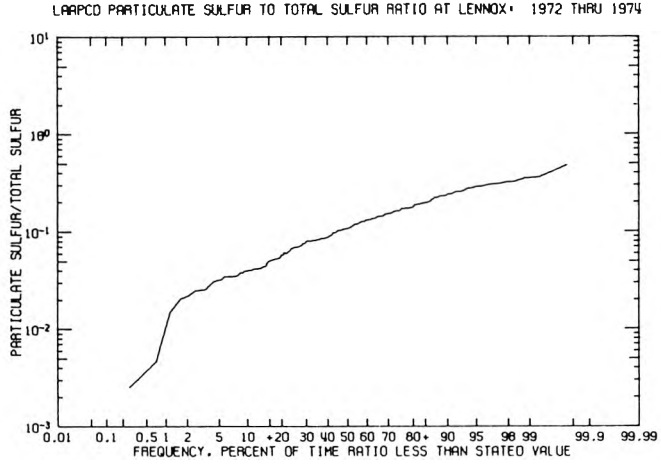



FIGURE B6.11

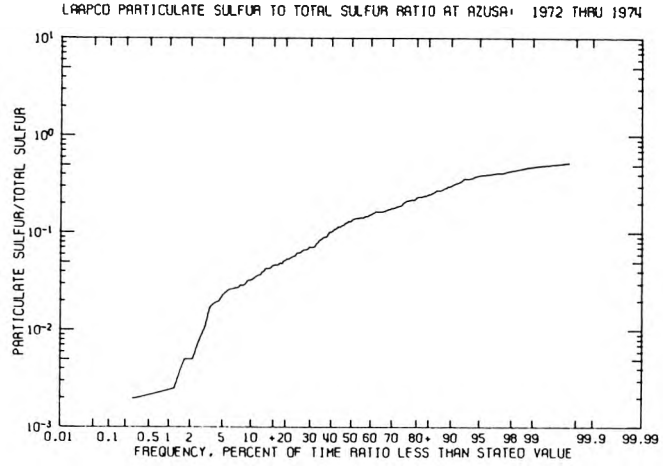



FIGURE B6.12

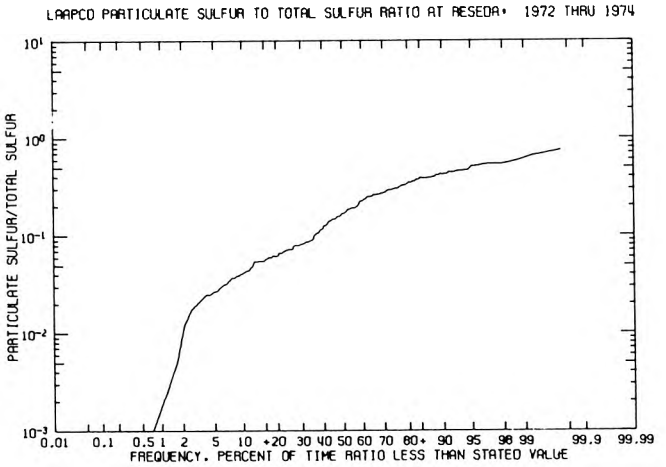



FIGURE B6.13

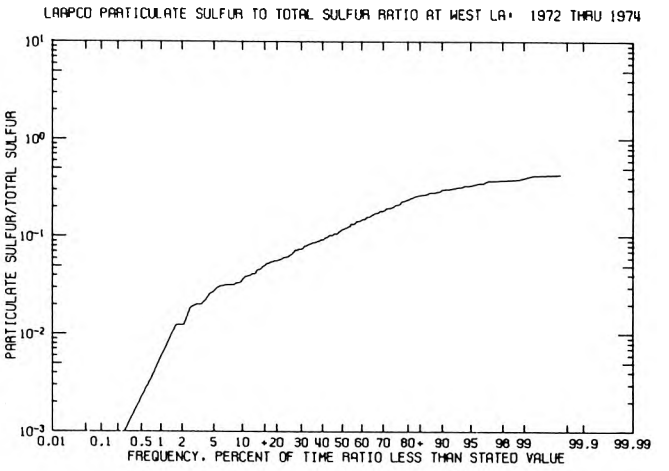



FIGURE B6.14

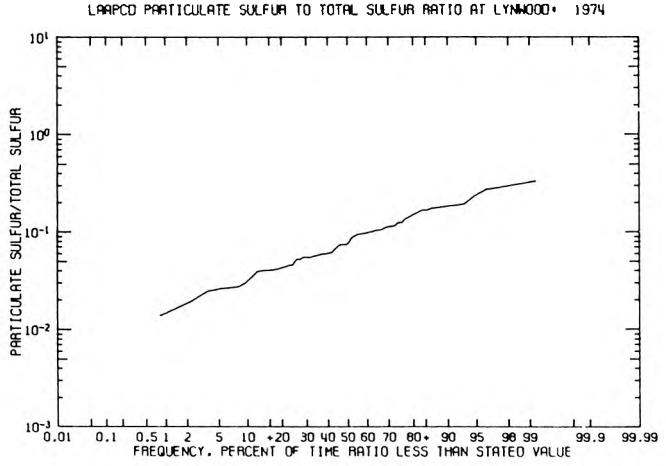



FIGURE B6.15

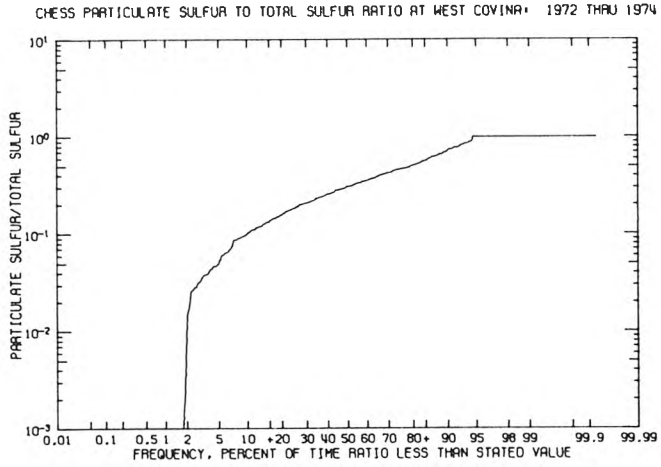



FIGURE B6.16

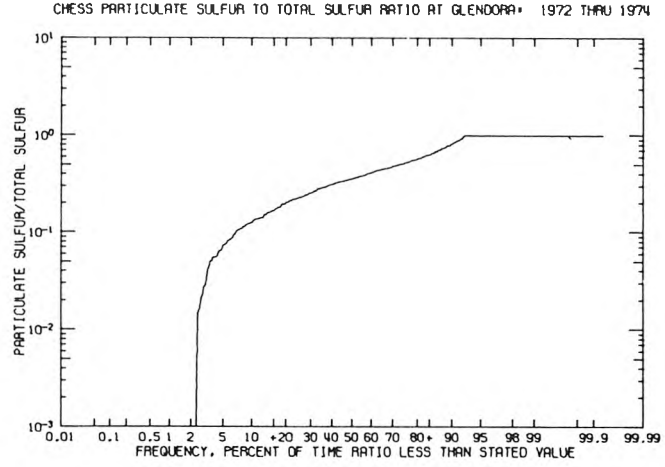



FIGURE B6.17

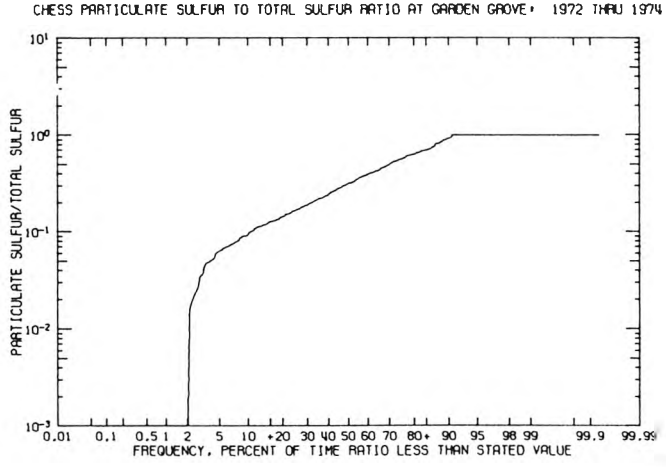



FIGURE B6.18

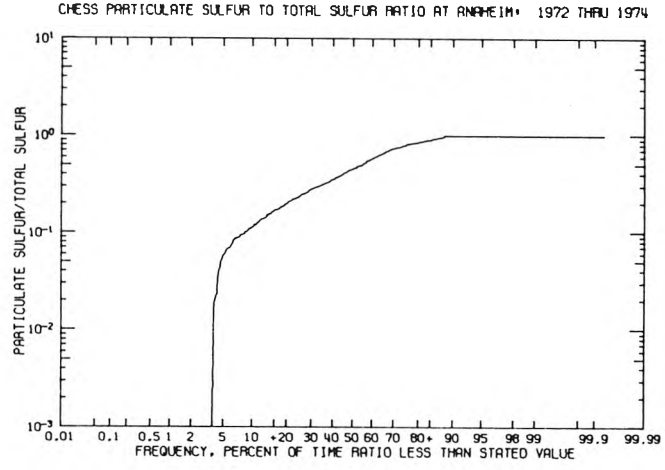



FIGURE B6.19

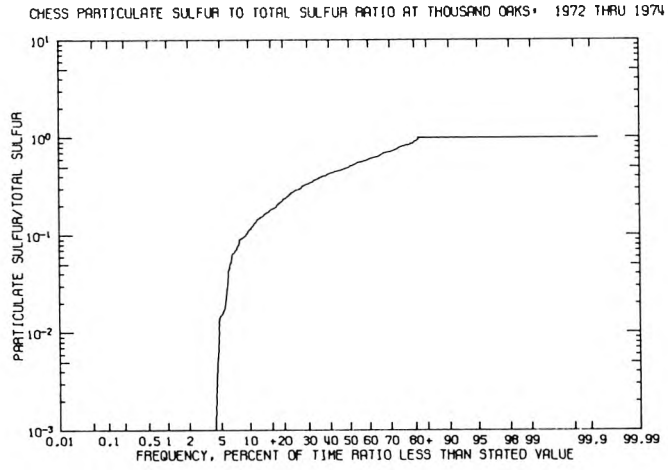



FIGURE B6.20

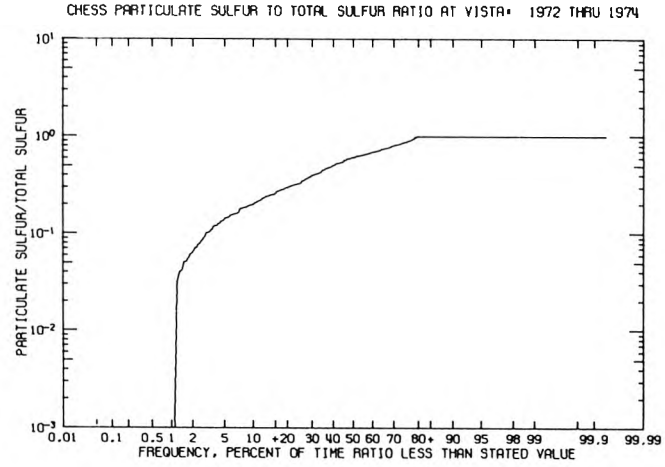



FIGURE B6.21

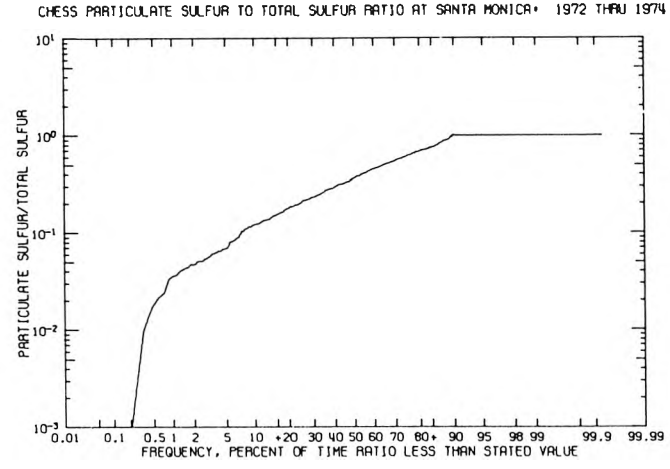



FIGURE B6.22

# APPENDIX B7

## MONTHLY MEAN VALUES OF THE RATIO OF PARTICULATE SULFUR TO TOTAL SULFUR, COMPARED TO MONTHLY VALUES OF THE RATIO OF MEAN PARTICULATE SULFUR TO MEAN TOTAL SULFUR: 1972 - 1974

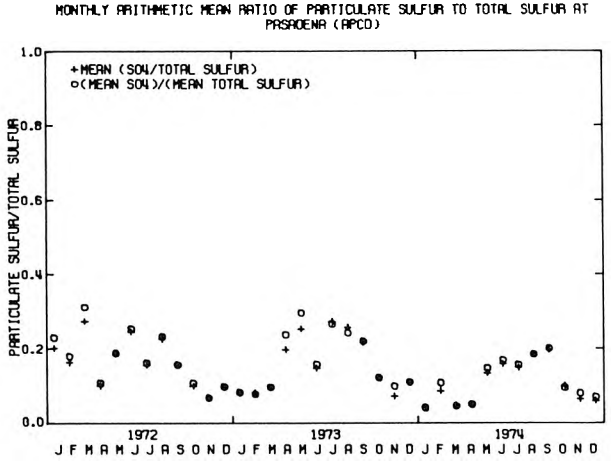



FIGURE B7.1

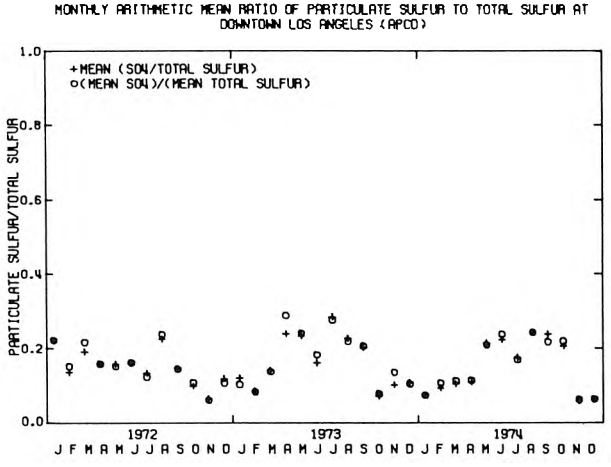



FIGURE B7.2

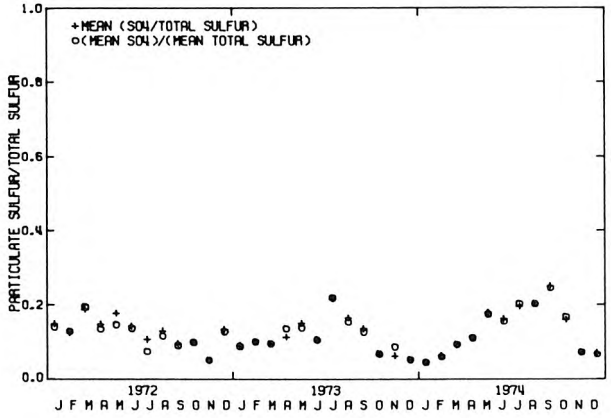



FIGURE B7.3

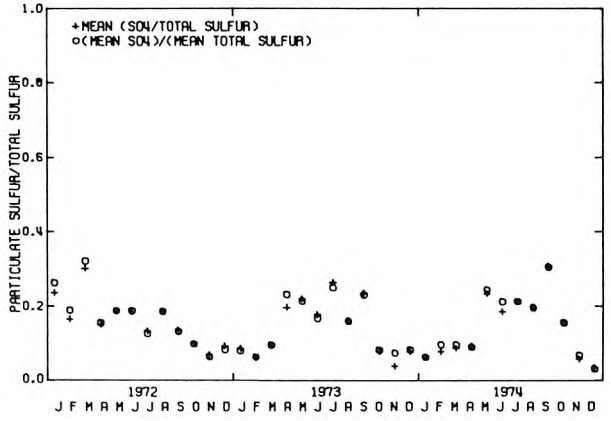



FIGURE B7.4

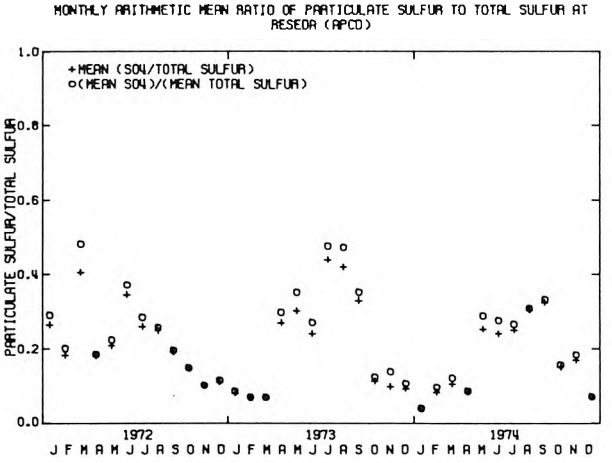



FIGURE B7.5

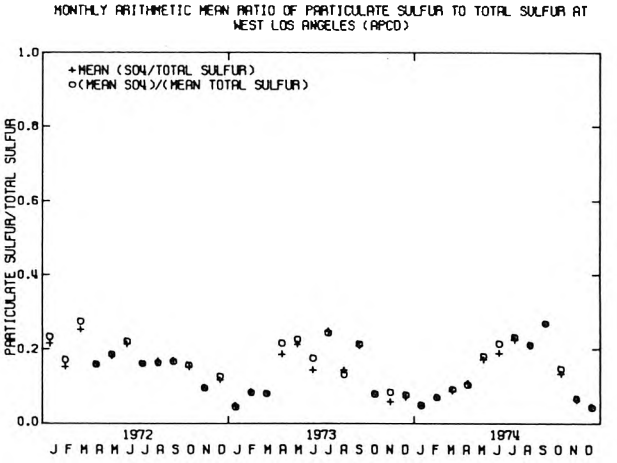



FIGURE B7.6

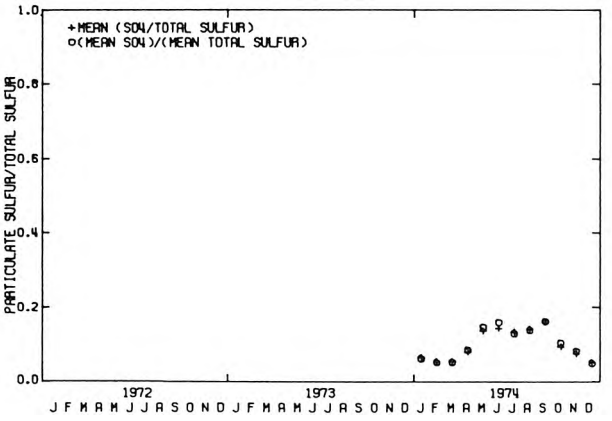



FIGURE B7.7

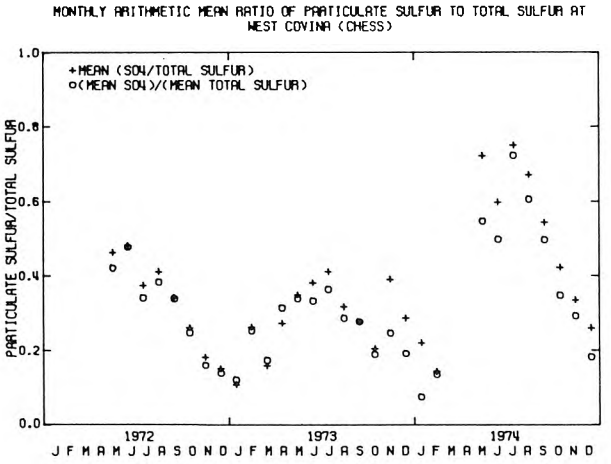



FIGURE B7.8

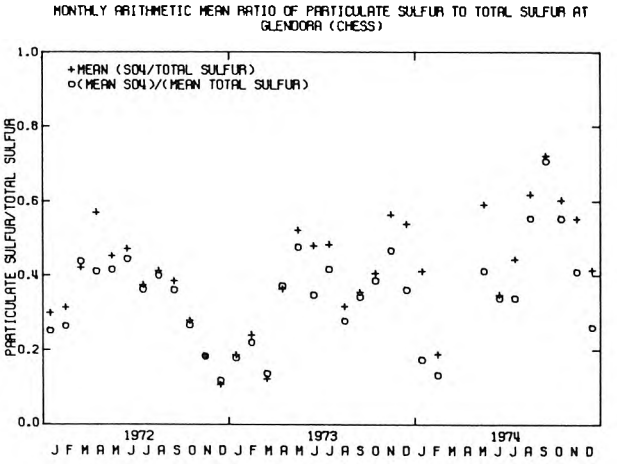



FIGURE B7.9

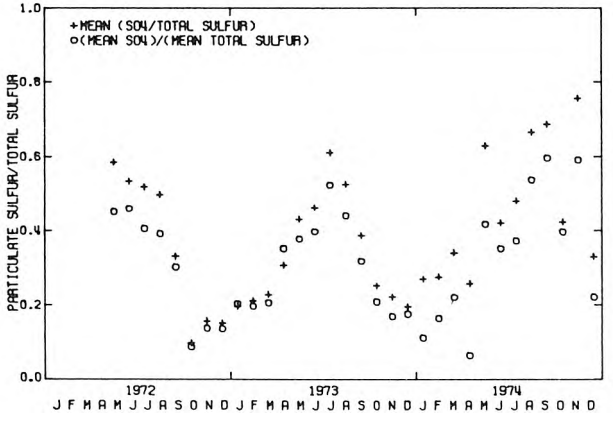



FIGURE B7.10

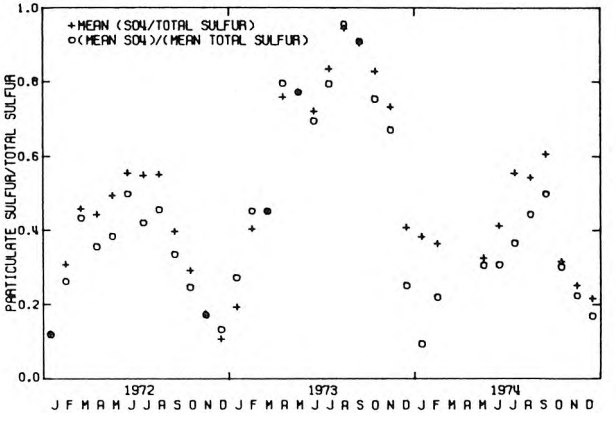



FIGURE B7.11

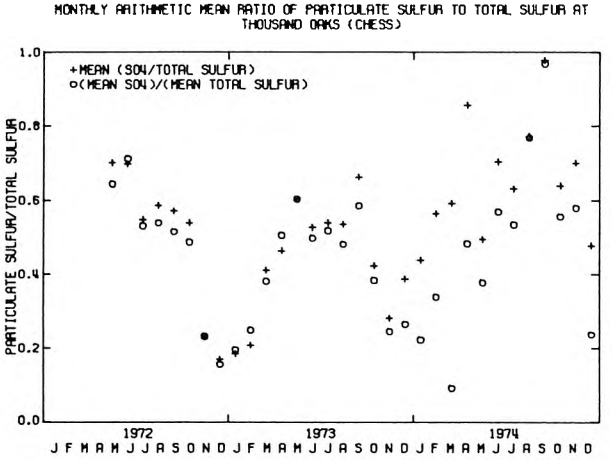



FIGURE B7.12

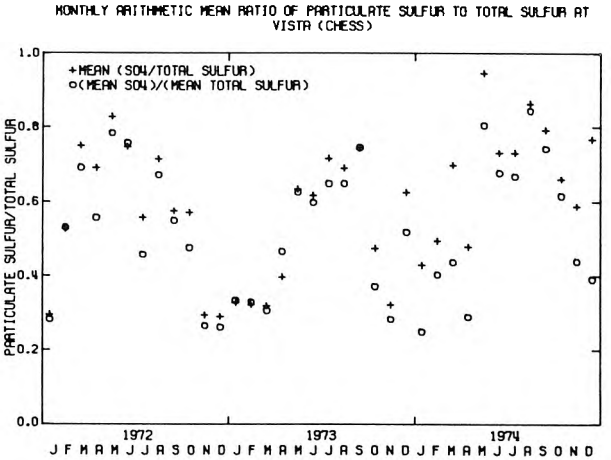



FIGURE B7.13

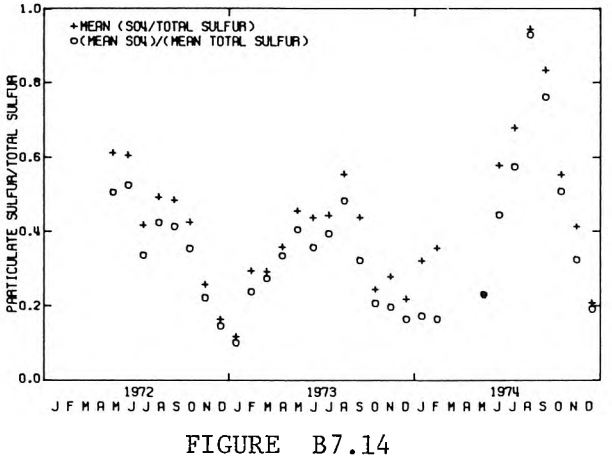



FIGURE B7.14

# APPENDIX B8

## DESCRIPTION OF THE DATA BASE USED IN THE STUDY OF SULFATE CORRELATION WITH METEOROLOGICAL AND POLLUTANT VARIABLES

| Symbol | Description | Units in Which Value is Stated | Averaging Time |
|---|---|---|---|
| $SO_4$ | Water soluble sulfate ion concentration extracted from hi vol filter | $\mu gm/m^3$ | 24 hr |
| Inv. Max. | Height of afternoon inversion base over downtown LA (estimated from morning sounding)[b] | 100's ft above msℓ | |
| Inv. Base | Height of early morning inversion base at LA Int'l Airport[b] | 100's ft above msℓ | |
| Wind Sp | Scalar average wind speed at downtown LA | mph | 24 hr |
| Sol Rad | Solar radiation intensity at downtown LA | $\frac{gm\ cal}{cm^2\ hr}$ | 24 hr |
| Max Temp | Maximum temperature reached at downtown LA | $^oF$ | |
| O3 Max | Instantaneous maxima of daily oxidant observations at downtown LA | pphm | |
| Avg O3 | Average of daily oxidant observations at downtown LA | ppm | 24 hr |
| $NO_2$ | Average of daily $NO_2$ observations at downtown LA | ppm | 24 hr |
| Total HC | Average of daily total hydrocarbon observations at downtown LA | ppm | 24 hr |
| $SO_2$ | Average of daily $SO_2$ observations at downtown LA | ppm | 24 hr |
| TSP | Total suspended particulate concentration at downtown LA | $\mu gm/m^3$ | 24 hr |
| (1-RH) | One minus the average of relative humidity observations at downtown LA. Relative humidity expressed in percent/100 | | 24 hr |

Notes: (a) Averages are taken for the 24 hour period corresponding to the sulfate sample schedule. Missing hourly data were replaced by linear interpolation between adjacent data points prior to averaging. 24 hour average relative humidity values are approximate since observations are taken for 14 hours daily, thus necessitating extensive interpolation.
(b) Detailed estimates of mixing depth for observations with inversion height above 5000 ft are not available. Mixing depth on those occasions will be estimated as 6667 ft.

# TABLE B8.1(a)

Statistical Description of Data Base
Used in Study of Sulfate Correlation with Meteorological
and Pollutant Variables

A. Data Base Incorporating all Complete Sets of Observations

Sampling Station is Downtown Los Angeles
Number of Complete Sets of Observations = 342
Time Period Spanned is August 1965 through December 1974

| | Variable | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $SO_4^=$ | Inv Max | Inv Base | Wind Speed | Solar Rad | Max Temp | Ozone Max | Avg Ozone | $NO_2$ | Total Hydrocarbons | $SO_2$ | TSP | (1-RH) |
| **Average** | 13.97 | 40.57 | 18.51 | 5.36 | 18.48 | 75.72 | 11.77 | 0.032 | 0.083 | 3.32 | 0.019 | 157.26 | 0.36 |
| **Standard Deviation** | 11.60 | 17.09 | 19.55 | 1.19 | 6.80 | 10.08 | 7.67 | 0.017 | 0.039 | 1.11 | 0.007 | 59.20 | 0.17 |

Linear Correlation Between Variables

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SO_4^=$ | 1.00 | -0.55 | -0.04 | -0.04 | -0.04 | -0.07 | 0.09 | 0.18 | 0.11 | -0.06 | 0.25 | 0.31 | -0.49 |
| Inv Max | -0.55 | 1.00 | 0.30 | 0.11 | -0.16 | -0.15 | -0.24 | -0.29 | -0.12 | -0.08 | -0.27 | -0.32 | 0.46 |
| Inv Base | -0.04 | 0.30 | 1.00 | 0.45 | -0.08 | -0.39 | -0.36 | -0.24 | -0.46 | -0.47 | -0.39 | -0.37 | -0.26 |
| Wind Sp | -0.04 | 0.11 | 0.45 | 1.00 | 0.31 | -0.10 | -0.17 | -0.03 | -0.51 | -0.58 | -0.42 | -0.39 | -0.06 |
| Sol Rad | -0.04 | -0.16 | -0.08 | 0.31 | 1.00 | 0.42 | 0.45 | 0.51 | -0.15 | -0.13 | -0.10 | -0.10 | 0.02 |
| Max Temp | -0.07 | -0.15 | -0.39 | -0.10 | 0.42 | 1.00 | 0.59 | 0.52 | 0.24 | 0.25 | 0.19 | 0.16 | 0.33 |
| O3 Max | 0.09 | -0.24 | -0.36 | -0.17 | 0.45 | 0.59 | 1.00 | 0.92 | 0.34 | 0.33 | 0.22 | 0.32 | 0.11 |
| Avg O3 | 0.18 | -0.29 | -0.24 | -0.03 | 0.51 | 0.52 | 0.92 | 1.00 | 0.17 | 0.17 | 0.10 | 0.22 | -0.02 |
| $NO_2$ | 0.11 | -0.12 | -0.46 | -0.51 | -0.15 | 0.24 | 0.34 | 0.17 | 1.00 | 0.73 | 0.49 | 0.64 | 0.27 |
| Total HC | -0.06 | -0.08 | -0.47 | -0.58 | -0.13 | 0.25 | 0.33 | 0.17 | 0.73 | 1.00 | 0.42 | 0.61 | 0.31 |
| $SO_2$ | 0.25 | -0.27 | -0.39 | -0.42 | -0.10 | 0.19 | 0.22 | 0.10 | 0.49 | 0.42 | 1.00 | 0.47 | 0.04 |
| TSP | 0.31 | -0.32 | -0.37 | -0.39 | -0.10 | 0.16 | 0.32 | 0.22 | 0.64 | 0.61 | 0.47 | 1.00 | 0.09 |
| (1-RH) | -0.49 | 0.46 | -0.26 | -0.06 | 0.02 | 0.33 | 0.11 | -0.02 | 0.27 | 0.31 | 0.04 | 0.09 | 1.00 |

Correlation Between Natural Log of Variables

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SO_4^=$ | 1.00 | -0.60 | 0.26 | -0.03 | -0.03 | 0.009 | 0.22 | 0.31 | 0.14 | -0.01 | 0.22 | 0.38 | -0.50 |
| Inv Max | -0.60 | 1.00 | -0.02 | 0.09 | -0.12 | -0.12 | -0.32 | -0.33 | -0.16 | -0.10 | -0.29 | -0.35 | 0.44 |
| Inv Base | 0.26 | -0.02 | 1.00 | 0.48 | 0.02 | -0.24 | -0.21 | -0.02 | -0.50 | -0.55 | -0.35 | -0.33 | -0.48 |
| Wind Sp | -0.03 | 0.09 | 0.48 | 1.00 | 0.36 | -0.05 | -0.12 | 0.04 | -0.56 | -0.63 | -0.45 | -0.44 | -0.09 |
| Sol Rad | -0.03 | -0.12 | 0.02 | 0.36 | 1.00 | 0.37 | 0.57 | 0.57 | -0.09 | -0.08 | -0.06 | -0.03 | 0.16 |
| Max Temp | 0.009 | -0.12 | -0.24 | -0.05 | 0.37 | 1.00 | 0.49 | 0.45 | 0.20 | 0.21 | 0.16 | 0.15 | 0.27 |
| O3 Max | 0.22 | -0.32 | -0.21 | -0.12 | 0.57 | 0.49 | 1.00 | 0.91 | 0.30 | 0.27 | 0.24 | 0.35 | 0.04 |
| Avg O3 | 0.31 | -0.33 | -0.02 | 0.04 | 0.57 | 0.45 | 0.91 | 1.00 | 0.15 | 0.10 | 0.13 | 0.24 | -0.06 |
| $NO_2$ | 0.14 | -0.16 | -0.50 | -0.56 | -0.09 | 0.20 | 0.30 | 0.15 | 1.00 | 0.70 | 0.47 | 0.66 | 0.25 |
| Total HC | -0.01 | -0.10 | -0.55 | -0.63 | -0.08 | 0.21 | 0.27 | 0.10 | 0.70 | 1.00 | 0.43 | 0.62 | 0.27 |
| $SO_2$ | 0.22 | -0.29 | -0.35 | -0.45 | -0.06 | 0.16 | 0.24 | 0.13 | 0.47 | 0.43 | 1.00 | 0.48 | 0.04 |
| TSP | 0.38 | -0.35 | -0.33 | -0.44 | -0.03 | 0.15 | 0.35 | 0.24 | 0.66 | 0.62 | 0.48 | 1.00 | 0.10 |
| (1-RH) | -0.50 | 0.44 | -0.48 | -0.09 | 0.16 | 0.27 | 0.04 | -0.06 | 0.25 | 0.27 | 0.04 | 0.10 | 1.00 |

# TABLE B8.1(b)

Statistical Description of Data Base
Used in Study of Sulfate Correlation with Meteorological
and Pollutant Variables

B. Data Base Incorporating Observations Since Change in Sampling Schedule of September, 1970

Sampling Station is Downtown Los Angeles
Number of Complete Sets of Observations = 186
Time Period is September 1970 through December 1974

| | $SO_4^=$ | Inv Max | Inv Base | Wind Speed | Solar Rad | Max Temp | Variable Ozone Max | Avg Ozone | $NO_2$ | Total Hydrocarbons | $SO_2$ | TSP | (1-RH) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average | 16.15 | 40.84 | 20.15 | 5.56 | 17.49 | 75.46 | 9.67 | 0.028 | 0.081 | 3.15 | 0.019 | 151.19 | 0.36 |
| Standard Deviation | 13.11 | 16.67 | 20.19 | 1.31 | 6.68 | 11.12 | 6.52 | 0.015 | 0.039 | 1.04 | 0.008 | 61.26 | 0.16 |

Linear Correlation Between Variables

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SO_4^=$ | 1.00 | -0.54 | -0.05 | -0.13 | -0.04 | -0.13 | -0.13 | -0.19 | -0.12 | -0.007 | 0.34 | 0.33 | -0.55 |
| Inv Max | -0.54 | 1.00 | 0.35 | 0.20 | -0.09 | -0.14 | -0.23 | -0.22 | -0.19 | -0.16 | -0.39 | -0.35 | 0.40 |
| Inv Base | -0.05 | 0.35 | 1.00 | 0.44 | -0.20 | -0.38 | -0.41 | -0.25 | -0.45 | -0.45 | -0.38 | -0.37 | -0.26 |
| Wind Sp | -0.13 | 0.20 | 0.44 | 1.00 | 0.27 | -0.05 | -0.14 | 0.02 | -0.47 | -0.56 | -0.39 | -0.35 | 0.06 |
| Sol Rad | -0.04 | -0.09 | -0.20 | 0.27 | 1.00 | 0.50 | 0.51 | 0.55 | -0.12 | -0.11 | -0.06 | -0.09 | 0.11 |
| Max Temp | -0.13 | -0.14 | -0.38 | -0.05 | 0.50 | 1.00 | 0.59 | 0.50 | 0.18 | 0.14 | 0.17 | 0.06 | 0.35 |
| O3 Max | 0.13 | -0.23 | -0.41 | -0.14 | 0.51 | 0.59 | 1.00 | 0.91 | 0.24 | 0.20 | 0.26 | 0.18 | 0.15 |
| Avg O3 | 0.19 | -0.22 | -0.24 | 0.02 | 0.55 | 0.50 | 0.91 | 1.00 | 0.02 | -0.03 | 0.12 | 0.02 | 0.01 |
| $NO_2$ | 0.12 | -0.19 | -0.45 | -0.47 | -0.12 | 0.18 | 0.24 | 0.02 | 1.00 | 0.77 | 0.51 | 0.68 | 0.25 |
| Total HC | -0.007 | -0.16 | -0.45 | -0.56 | -0.11 | 0.14 | 0.20 | -0.03 | 0.77 | 1.00 | 0.42 | 0.67 | 0.27 |
| $SO_2$ | 0.34 | -0.39 | -0.38 | -0.39 | -0.06 | 0.17 | 0.26 | 0.12 | 0.51 | 0.42 | 1.00 | 0.50 | -0.06 |
| TSP | 0.33 | -0.35 | -0.37 | -0.35 | -0.09 | 0.06 | 0.18 | 0.02 | 0.68 | 0.67 | 0.50 | 1.00 | 0.08 |
| (1-RH) | -0.55 | 0.40 | -0.26 | 0.06 | 0.11 | 0.35 | 0.15 | 0.01 | 0.25 | 0.27 | -0.06 | 0.08 | 1.00 |

Correlation Between Natural Log of Variables

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SO_4^=$ | 1.00 | -0.62 | 0.27 | -0.09 | -0.007 | -0.10 | 0.26 | 0.32 | 0.08 | 0.004 | 0.37 | 0.35 | -0.66 |
| Inv Max | -0.62 | 1.00 | 0.07 | 0.19 | -0.07 | -0.08 | -0.33 | -0.26 | -0.21 | -0.14 | -0.42 | -0.39 | 0.40 |
| Inv Base | 0.27 | 0.07 | 1.00 | 0.43 | -0.13 | -0.25 | -0.34 | -0.09 | -0.50 | -0.51 | -0.31 | -0.37 | -0.51 |
| Wind Sp | -0.09 | 0.19 | 0.43 | 1.00 | 0.31 | 0.01 | -0.10 | 0.12 | -0.52 | -0.61 | -0.42 | -0.41 | 0.01 |
| Sol Rad | -0.007 | -0.07 | -0.13 | 0.31 | 1.00 | 0.38 | 0.59 | 0.58 | -0.05 | -0.05 | -0.03 | -0.01 | 0.22 |
| Max Temp | 0.10 | -0.08 | -0.25 | 0.01 | 0.38 | 1.00 | 0.43 | 0.37 | 0.13 | 0.12 | 0.13 | 0.04 | 0.28 |
| O3 Max | 0.26 | -0.33 | -0.37 | -0.10 | 0.59 | 0.43 | 1.00 | 0.89 | 0.24 | 0.20 | 0.32 | 0.26 | 0.07 |
| Avg O3 | 0.32 | -0.26 | -0.09 | 0.12 | 0.58 | 0.37 | 0.89 | 1.00 | 0.00 | -0.05 | 0.15 | 0.06 | -0.06 |
| $NO_2$ | 0.08 | -0.21 | -0.50 | -0.52 | -0.05 | 0.13 | 0.24 | 0.00 | 1.00 | 0.71 | 0.51 | 0.69 | 0.27 |
| Total HC | 0.004 | -0.14 | -0.51 | -0.61 | -0.05 | 0.12 | 0.20 | -0.05 | 0.71 | 1.00 | 0.42 | 0.67 | 0.28 |
| $SO_2$ | 0.37 | -0.42 | -0.31 | -0.42 | -0.03 | 0.13 | 0.32 | 0.15 | 0.51 | 0.42 | 1.00 | 0.54 | -0.08 |
| TSP | 0.35 | -0.39 | -0.37 | -0.41 | -0.01 | 0.04 | 0.26 | 0.06 | 0.69 | 0.67 | 0.54 | 1.00 | 0.09 |
| (1-RH) | -0.66 | 0.40 | -0.51 | 0.01 | 0.23 | 0.28 | 0.07 | -0.06 | 0.27 | 0.28 | -0.08 | 0.09 | 1.00 |

# APPENDIX C

## APPENDICES TO THE

## AIR QUALITY MODEL VALIDATION STUDY

# APPENDIX C1

## MONTHLY ARITHMETIC MEAN SULFATE

## CONCENTRATION ISOPLETHS FOR THE PERIOD 1972 THROUGH 1974

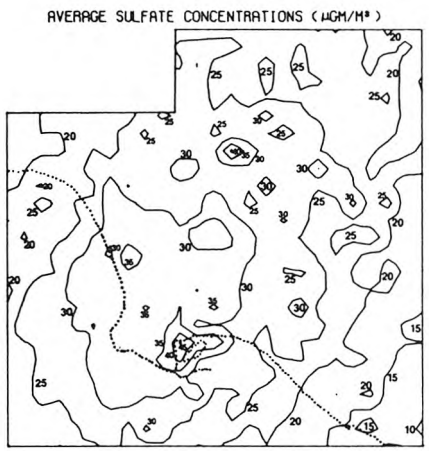



FIGURE C1.1

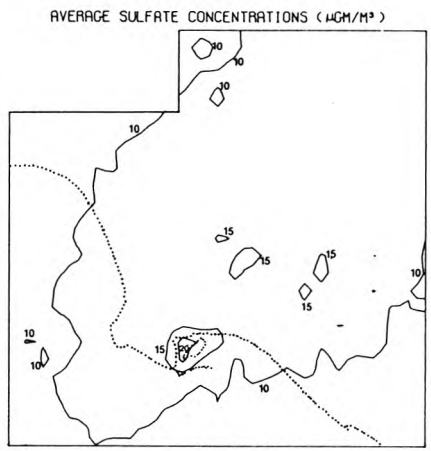



FIGURE C1.2

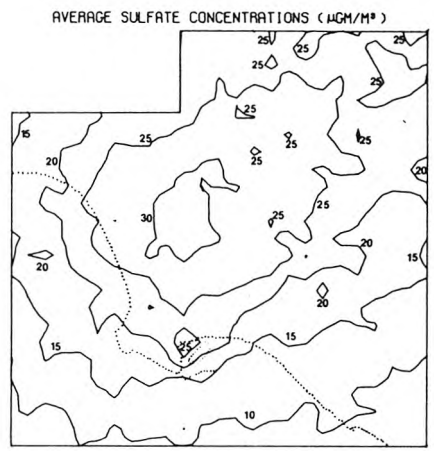



FIGURE C1.3

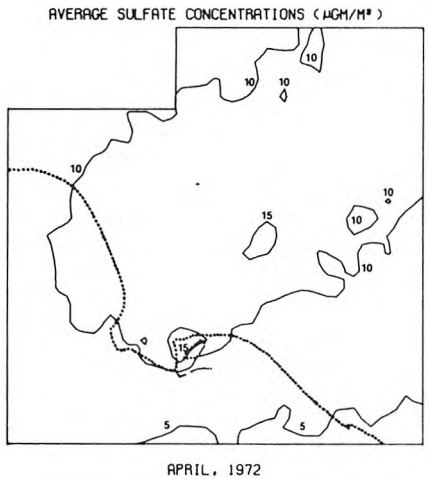



FIGURE C1.4

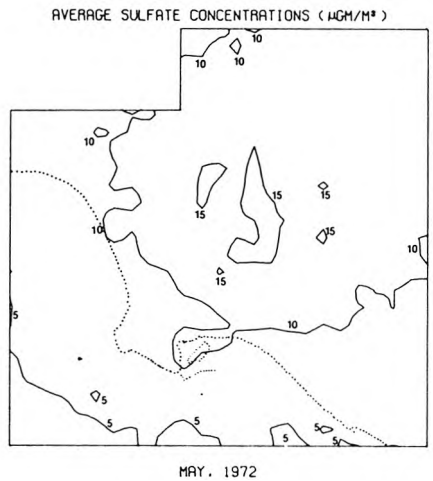



FIGURE C1.5

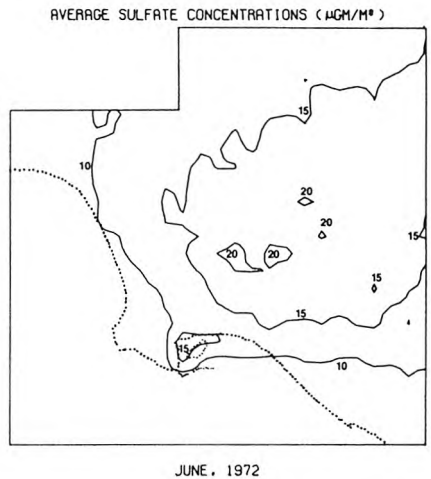



FIGURE C1.6

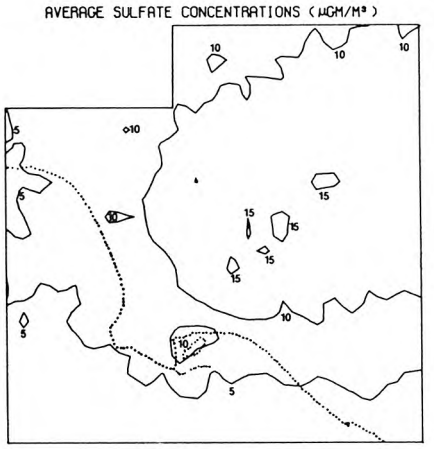



FIGURE C1.7

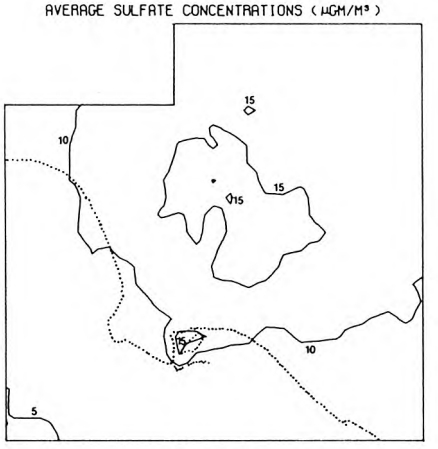



FIGURE C1.8

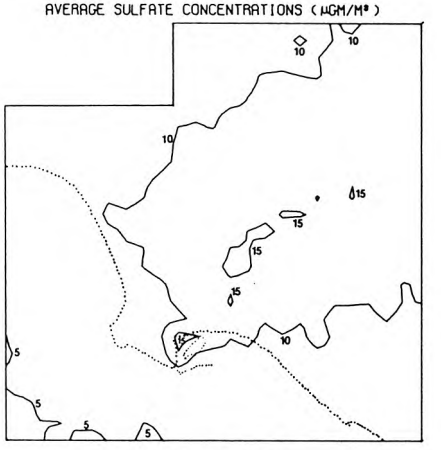



FIGURE C1.9

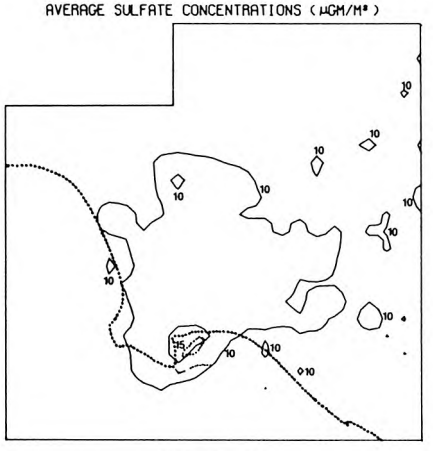



FIGURE C1.10

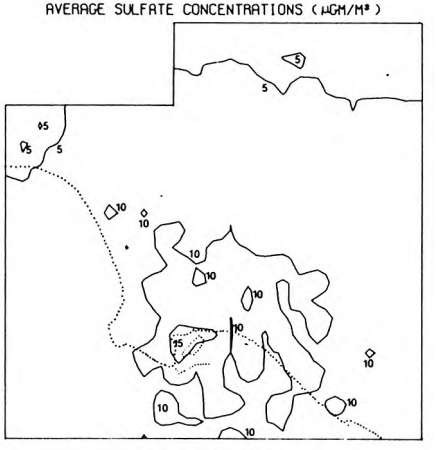



FIGURE C1.11

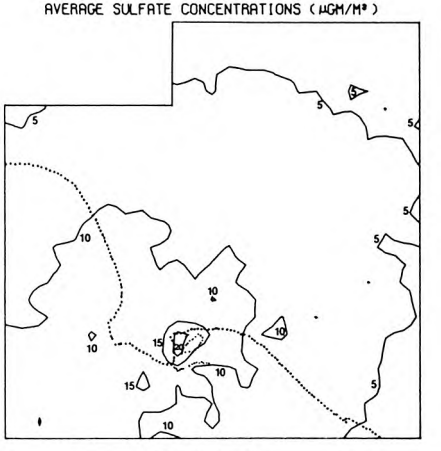



FIGURE C1.12

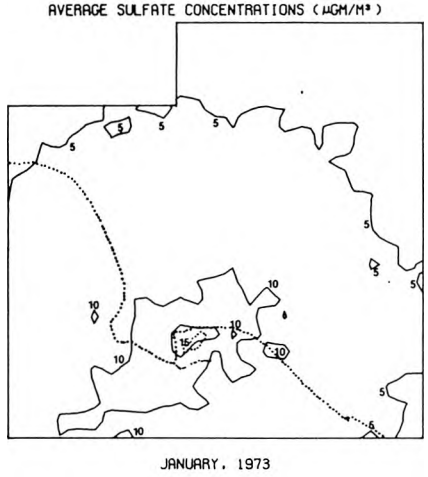



FIGURE C1.13

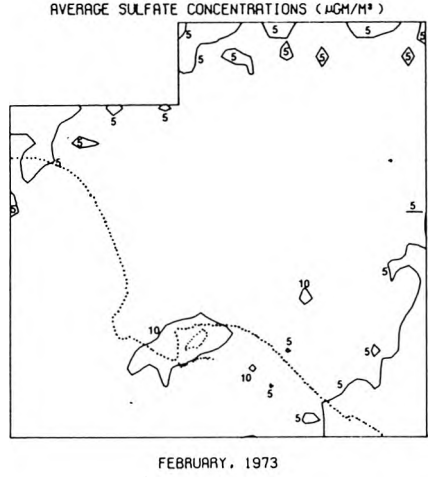



FIGURE C1.14

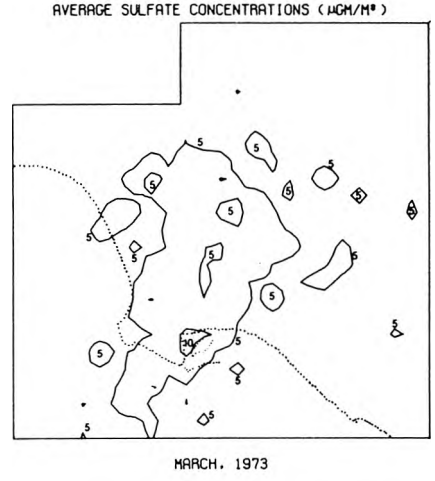



FIGURE C1.15

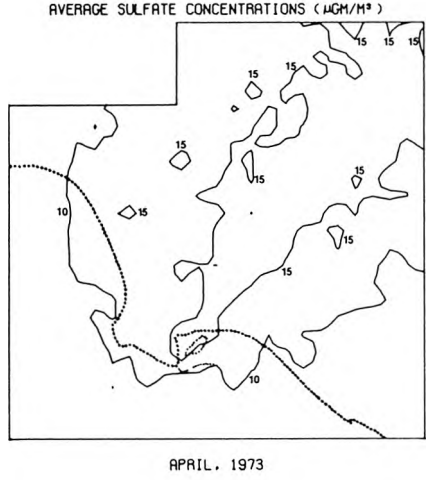



FIGURE C1.16

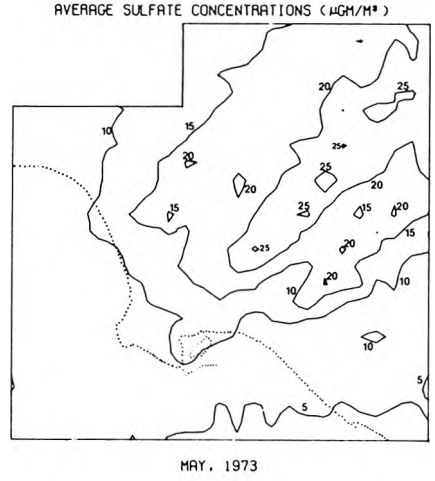



FIGURE C1.17

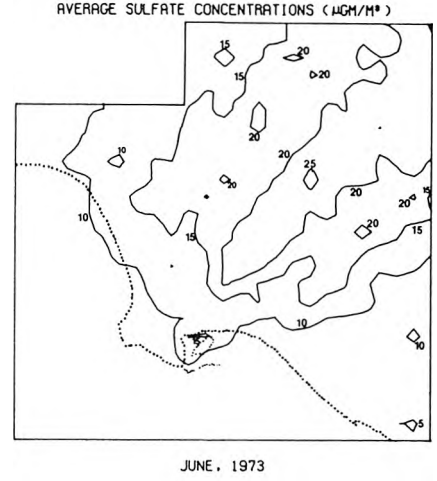
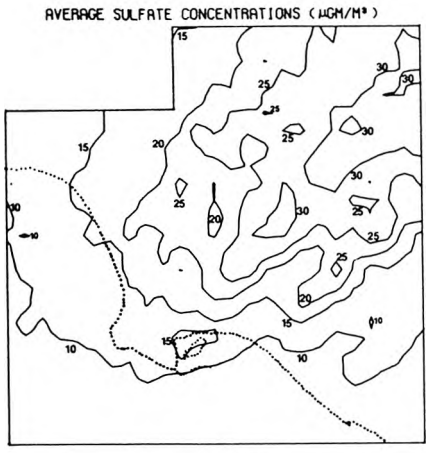
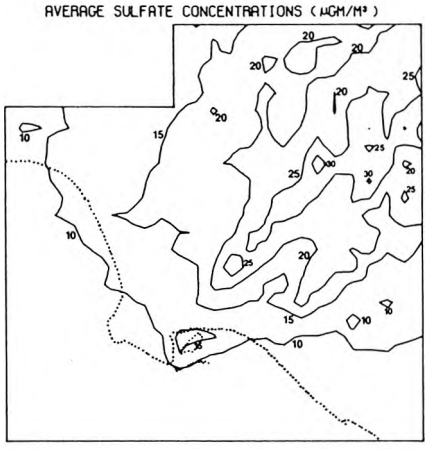



FIGURE C1.18



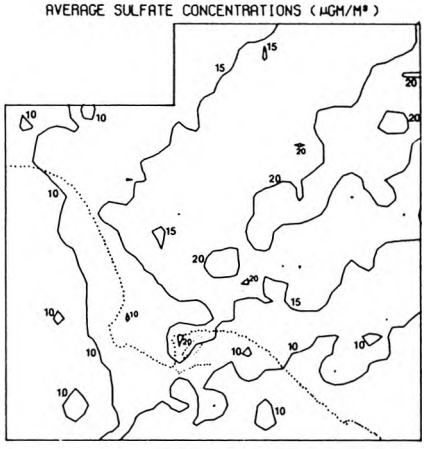

JULY, 1973

FIGURE C1.19



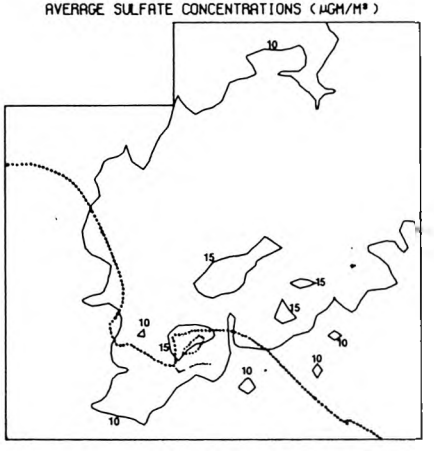

AUGUST, 1973

FIGURE C1.20



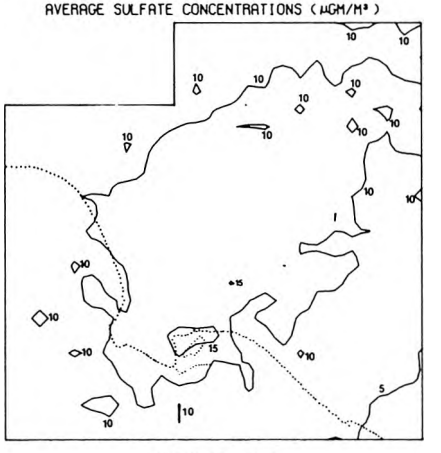

SEPTEMBER, 1973

FIGURE C1.21



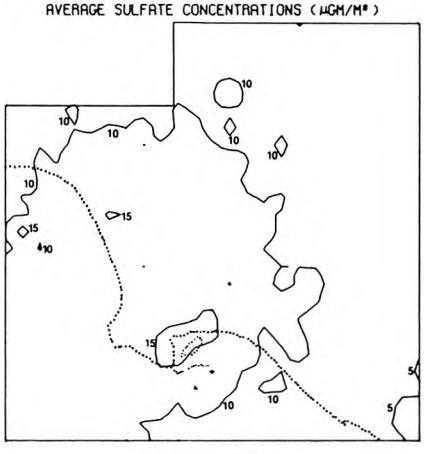

OCTOBER, 1973

FIGURE C1.22




NOVEMBER, 1973

FIGURE C1.23




DECEMBER, 1973

FIGURE C1.24

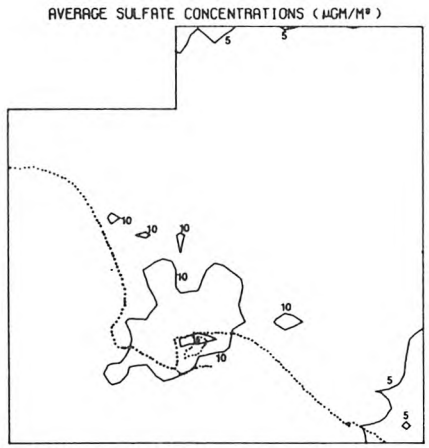



FIGURE C1.25

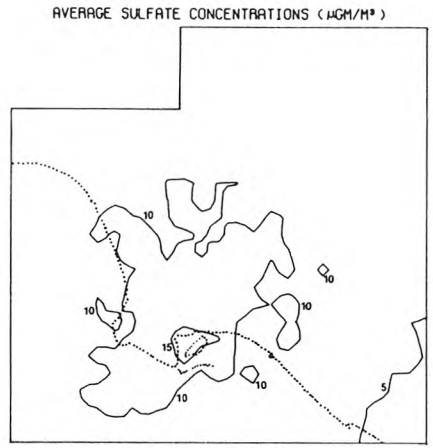



FIGURE C1.26

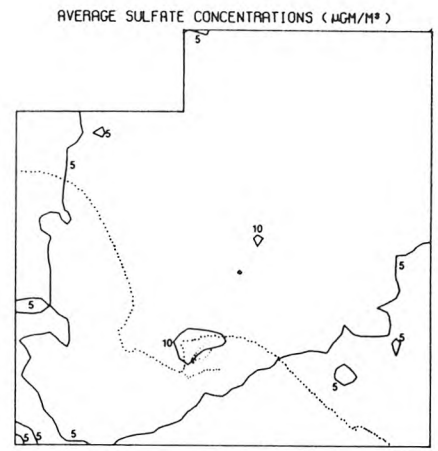



FIGURE C1.27

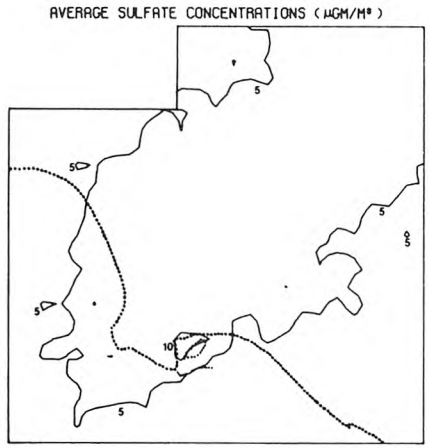



FIGURE C1.28

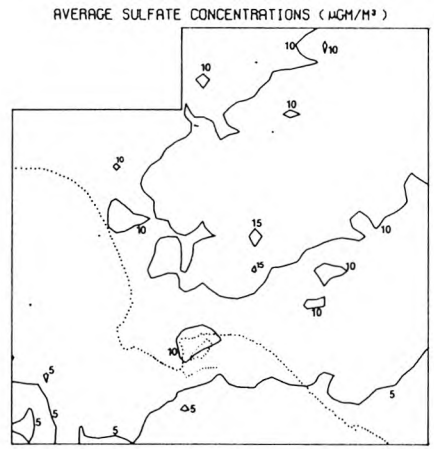



FIGURE C1.29

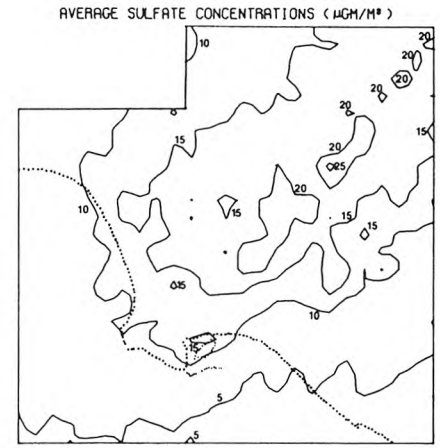
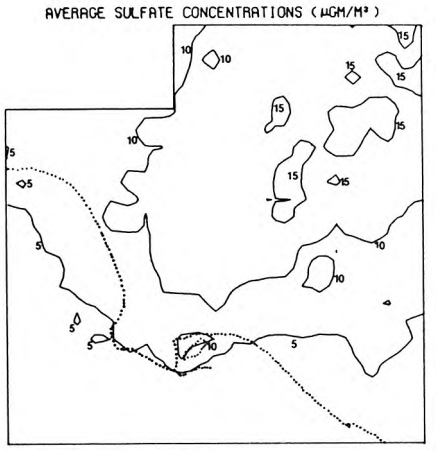
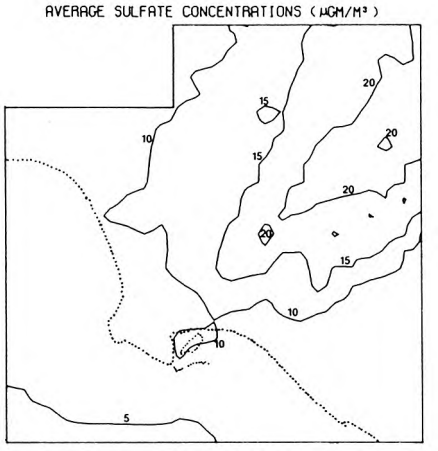



FIGURE C1.30



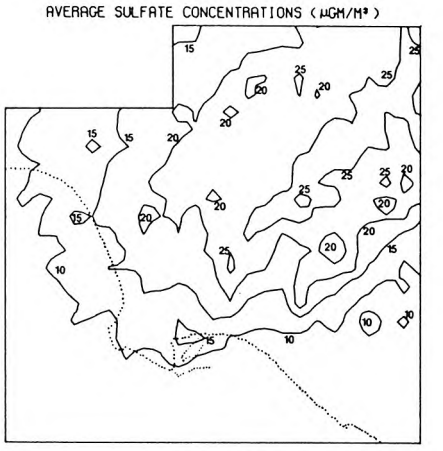

JULY, 1974

FIGURE C1.31



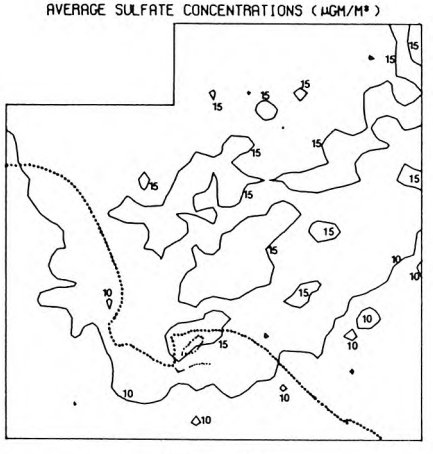

AUGUST, 1974

FIGURE C1.32



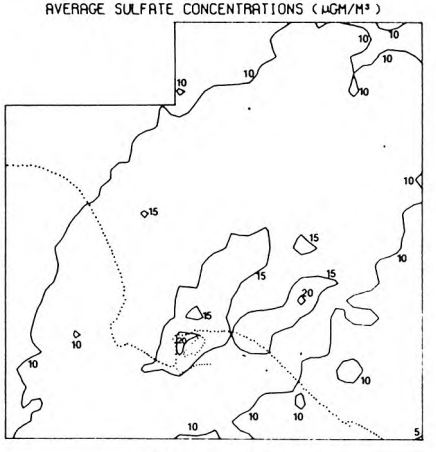

SEPTEMBER, 1974

FIGURE C1.33



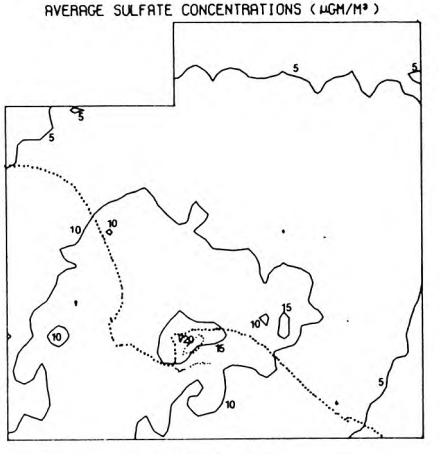

OCTOBER, 1974

FIGURE C1.34




NOVEMBER, 1974

FIGURE C1.35




DECEMBER, 1974

FIGURE C1.36

# APPENDIX C2

## OBSERVED VERSUS PREDICTED VALUES OF THE RATIO OF SULFATES TO TOTAL SULFUR OXIDES

As was noted in Chapter 2, it is more convenient to model the ratio of average sulfate to average total sulfur, $\bar{f}_s$, than it is to predict average values of $f_s$ for each month. These two particulate sulfur to total sulfur ratio statistics were compared in Appendix B , and found to display similar seasonal trends. Figures C2.1 through C2.11 compare simulation model results for monthly values of $\bar{f}_s$ to observations on $\bar{f}_s$ at all CHESS and LAAPCD monitoring stations within our receptor zone.

A comparison of $\bar{f}_s$ predictions to observations in the Eastern San Gabriel Valley at Azusa and Glendora serves to test our hypotheses about the nature of the sampling network biases. Air quality model results for $\bar{f}_s$ at these nearby locations are very similar, as shown in Figures C2.1 and C2.2. The LAAPCD monitoring network rounds $SO_2$ measurements which are below their minimum detection limit up to 26 $\mu gm/m^3$. This raises the average of total $SO_x$ observations at Azusa and lowers the value of $\bar{f}_s$ observed. As expected, model predictions for $\bar{f}_s$ at Azusa fall above the reported observations. Predictions and observations on $\bar{f}_s$ at Azusa both display similar seasonal trends, which is encouraging. The CHESS monitoring station at Glendora used a sulfur dioxide sampling method which also has minimum detection limit problems. In contrast to the LAAPCD practice, the CHESS network

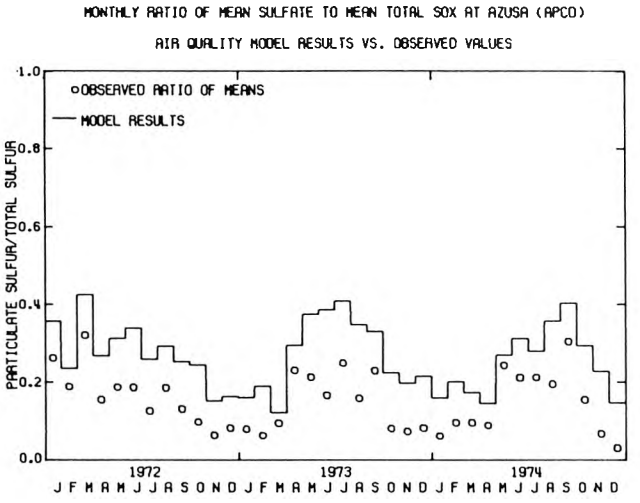



FIGURE C2.1

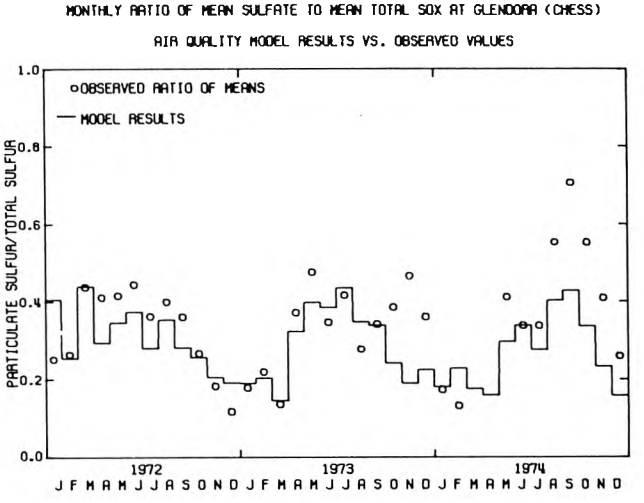



FIGURE C2.2

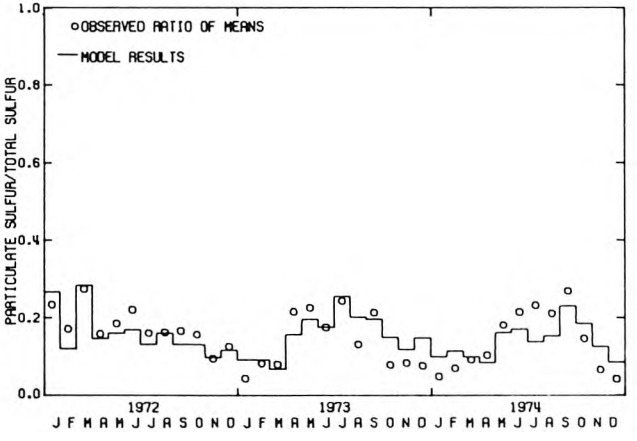



FIGURE C2.3

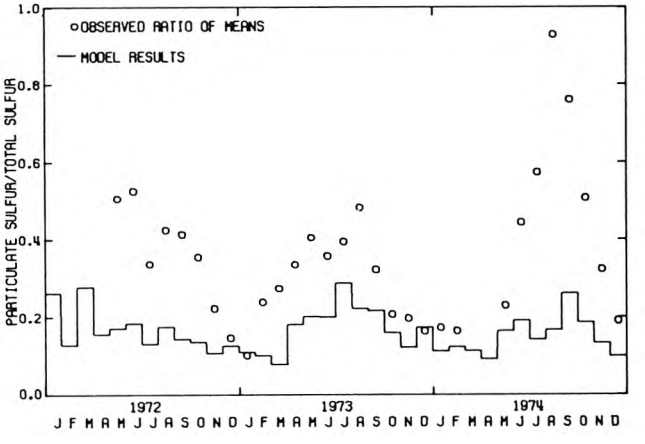



FIGURE C2.4

attempts to report a closest estimate of $SO_2$ concentrations which are below their nominal detection limit without truncation or round-up. However, systematic underestimation of $SO_2$ levels at low $SO_2$ concentrations is likely using the West-Gaeke $SO_2$ sampling method if reagent volume and airflow rate are not matched to the expected ambient $SO_2$ concentrations, or if close control is not maintained over the time-temperature history of the sample. Model results for $f_{\bar{s}}$ at Glendora are generally lower than observations, as expected. Observations on $f_{\bar{s}}$ match predictions closely at Glendora until late 1973. In October 1973, model predictions at both locations and measured $f_{\bar{s}}$ values at Azusa begin a short term decline, while $f_{\bar{s}}$ measurements at Glendora begin to rise. From that point onward, comparison of model results to $f_{\bar{s}}$ observations at Glendora becomes erratic. One suspects that the CHESS sampling protocol was changed.

A second comparison of nearby CHESS and LAAPCD air monitoring station data to model predictions for $f_{\bar{s}}$ is possible near West Los Angeles. Figures C2.3 and C2.4 show results obtained at the CHESS station in Santa Monica versus the measurements made at the LAAPCD station in West Los Angeles. Model results closely match LAAPCD observations at West Los Angeles and fall below CHESS data at Santa Monica.

In order to test the accuracy of model predictions for $f_{\bar{s}}$, it is going to be necessary to find a monitoring site which is known to experience high enough $SO_2$ concentrations that detection limit problems will be minimized. None of the CHESS stations are located near major

$SO_2$ sources. However the LAAPCD station at Lennox is adjacent to a busy freeway and is directly downwind of two power plants, an oil refinery, and Los Angeles International Airport. When model results at Lennox are compared to observations in Figure C2.5, excellent agreement is noted.

Model predictions for $f_{\overline{s}}$ fall below the LAAPCD monitoring results at downtown Los Angeles. That is the only LAAPCD station where model predictions do not confirm the suggested sampling bias in the LAAPCD $SO_2$ data. Reference to the emissions inventory of Chapter 4 and Appendix A2 suggests one likely source for this problem. $SO_x$ emissions at downtown Los Angeles are dominated by a mobile source $SO_x$ emission density comparable to many of our industrial point sources. With such large emissions rates located at ground level, total $SO_x$ air quality at the downtown monitoring site will be controlled by mobile sources located within the same receptor cell as the monitoring station. As mentioned in Chapter 5, the air quality simulation was not constructed with the intention of accurately reproducing concentrations in the extreme near-field. No sub-grid scale processes are embedded in the model. In spite of that, the model reproduces reasonable total sulfur concentration in most parts of the airshed.

Therefore, the emissions inventory was reviewed to see if there was anything unusual about the emissions estimates at downtown Los Angeles. It was found that a large fraction of the $SO_x$ emissions from within the receptor cell containing the downtown monitoring site arise from one of the few railroad switching yards in the air basin.

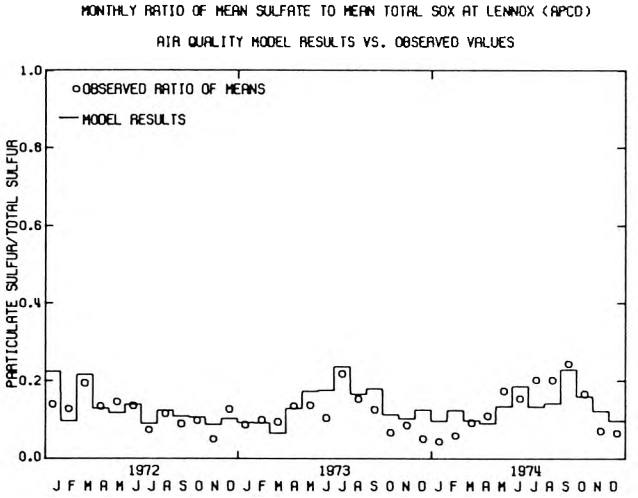



FIGURE C2.5

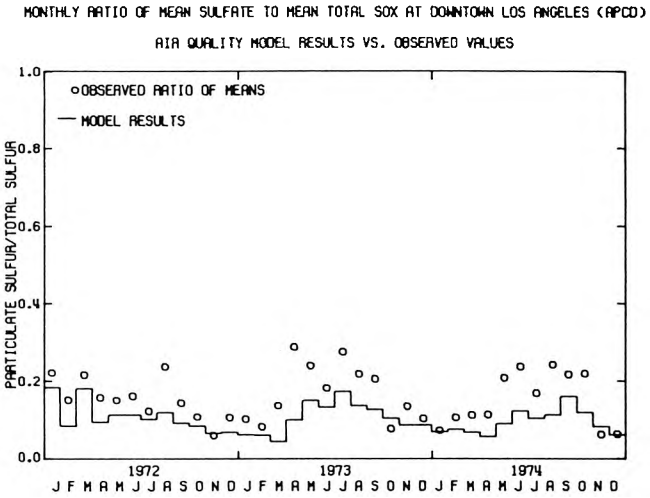



FIGURE C2.6

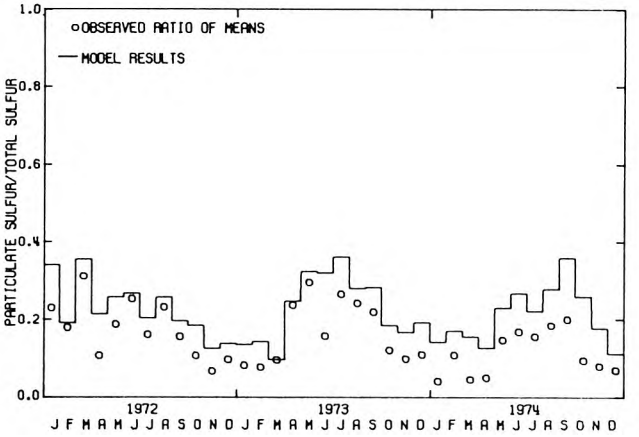



FIGURE C2.7

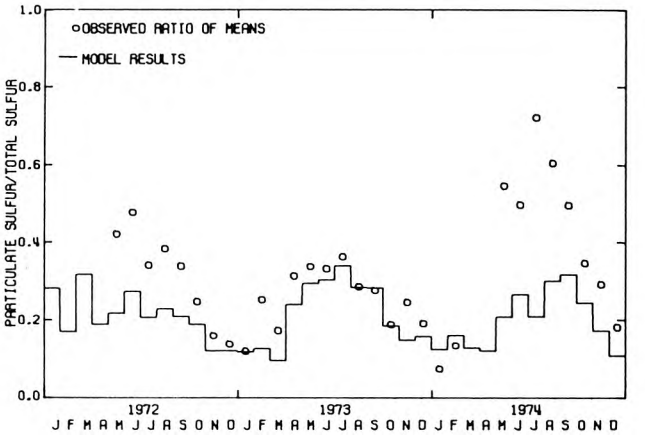



FIGURE C2.8

Emissions estimates for railroads were obtained in Appendix A2 by a rapid survey emission inventory technique and not from the higher quality site-specific information used throughout most of our other source classes. That railroad switching yard may well account for much of the over-estimate in total $SO_x$ air quality at the downtown monitoring site.

It is also worth noting that the downtown Los Angeles monitoring station is located on the upper floors of a tall building, about 20 meters above ground level. While that is still below the minimum mixing depth reported by the LAAPCD, the actual minimum mixing depth at night might be lower on occasion. Such surface inversions at night could trap pollutants below the level of the monitoring station, yielding lower $SO_2$ concentration measurements than would be the case at a ground level monitoring site in the same location.

Data at the remaining LAAPCD and CHESS air monitoring stations fall to the expected side of the model predictions for $f_s$. The comparison between model results and observations at the CHESS stations at Garden Grove and Anaheim is poor in the summer. This is due in part to our underprediction of sulfate levels at those locations. But more importantly, the $f_s$ values measured at these two locations are extremely suspect. Those stations are located within two miles of each other, which means that they could have been located within a single grid cell if desired when our grid system was established. Observations on $f_s$ at those two sites are so

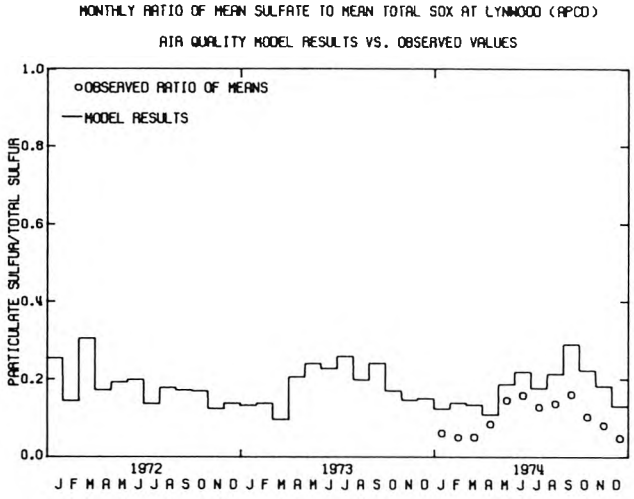



FIGURE C2.9

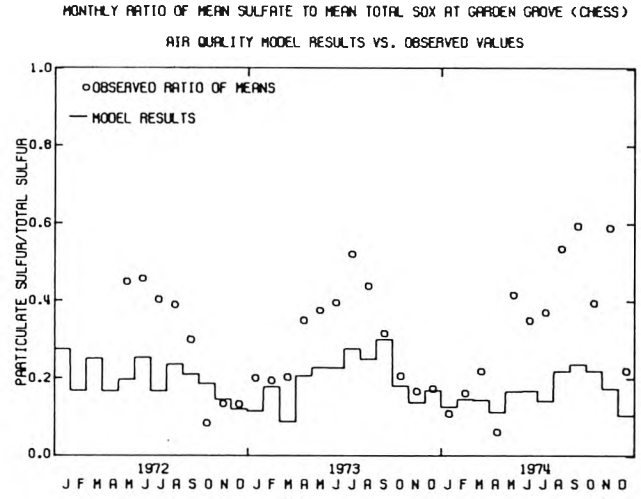



FIGURE C2.10

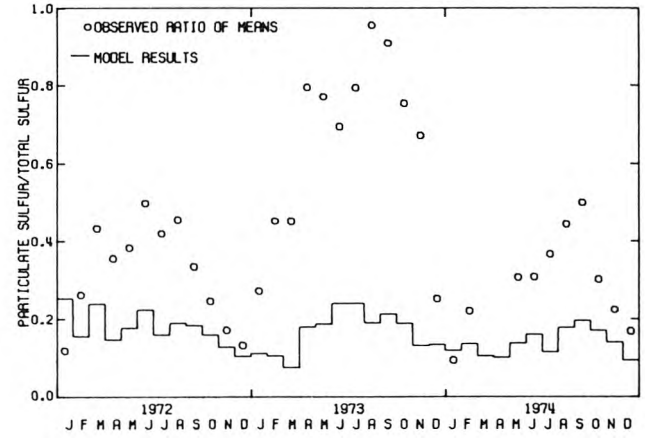



FIGURE C2.11

different that one suspects the accuracy of the $SO_2$ measurements involved, or the representativeness of the monitoring site locations.

Additional data on $f_s$ which are relatively free of minimum detection limit problems are available from the ACHEX Study (Hidy, et al, 1975). These data are compared to model predictions in Table C2.1. Close agreement is obtained at Dominguez Hills and Pomona. ACHEX values for West Covina are below model estimates during July 1973. Differences of that magnitude could easily arise from the fact that the ACHEX program did not sample for the entire month or from the fact that model results are for the ratio of mean sulfate to mean total sulfur oxides, while the ACHEX data are for the average of the ratio of particulate sulfur oxides to total sulfur.

It is concluded that model predictions for the ratio of particulate sulfur oxides to total sulfur oxides cannot be verified as closely as model predictions for sulfate air quality. This situation arises from the unavailability of sensitive sulfur dioxide air quality data. However, on the basis of what can be said from comparison to available monitoring data, most indications are that the model is working well within the context of this application.

TABLE C2.1

Particulate Sulfur to Total Sulfur Ratios:
Comparison of Simulation Model Results
to Measurements from the ACHEX Study

| Location | Month | ACHEX Data on $\overline{f}_s$ (a) | | Simulation Model $f_s$ | Grid Square |
|---|---|---|---|---|---|
| | | Day | Night | | |
| Dominguez Hills | October 1973 | 0.119 | 0.119 | 0.13 | I11-J11 |
| West Covina | July 1973 | 0.18 | 0.24 | 0.34 | I21-J18 |
| Pomona | August 1973 | 0.27 | 0.31 | 0.29 | I25-J18 |

(a) From Table 4-1 of Volume IV of the ACHEX Study (Hidy, et al., 1975)

# APPENDIX C3

## ERRATA FOR CHAPTER 5: A SULFUR OXIDES OMISSION INVENTORY

A series of quality control checks were performed on the model results to detect any minor errors which might escape a visual screening of the data. It was found that emissions from a subset of members of the miscellaneous stationary source category had been inadvertently deleted during the source class recombination step prior to execution of the model. The error occurred only in alternate months (February, April, June, etc.) and involved only 2% of the emissions within the inventory when it did occur. From a comparison of model results for months with and without the truncated inventory, an upper limit could be placed on the effect of the omission. The loss to the three year average sulfate air quality level predicted at pollutant monitoring stations ranged from 0.08 to 0.29 $\mu gm/m^3$ $SO_4^=$, with an average reduction over all stations of 0.15 $\mu gm/m^3$. To put that in perspective, the bias introduced is about 1% of the total average sulfate level in the air basin, and would alter the graphs of Chapter 5 section 5.4 by about the width of the pen used to plot them. Model output from one repetition to another varies by more than that amount due to the random number generators employed. None of our peak sulfate months (January 1972, March 1972, July 1973, September 1974) were affected. It was concluded that model validation results are insensitive to the omission. Corrective action will be taken prior to control strategy analysis.

# APPENDIX D

## APPENDICES TO THE VISIBILITY STUDY

# APPENDIX D1

## SOME PREVIOUS INVESTIGATIONS OF VISIBILITY AT LOS ANGELES

A number of investigators have reviewed visibility observations at Los Angeles with an eye toward determining the causes of reduced visual range. Long-term trends in visibility at Los Angeles are discussed by Neiburger (1955); Kauper, Holmes and Street (1955); Keith (1964); and Keith (1970). These studies conclude that visibility definitely deteriorated at Los Angeles during the period of industrialization which accompanied World War II. Several of these authors observe that this trend toward reduced visibility had been partially reversed by the early 1950's as a result of the initial imposition of pollution controls following the war years. This improvement was apparently not permanent. The most recent study (Keith, 1970) concludes that average noontime visibility at downtown Los Angeles had deteriorated over the past 37 years, and that the trend in this average was still downward as of 1969. Keith (1970) shows that this decline in average visibility is accompanied by a strong increasing trend in the number of days per year with visibilities falling into the ranges 1-1/2 to 2-1/2 miles, and 3 to 6 miles. It is of interest to note that this is the same portion of the cumulative distribution of visibilities which our regression model predicts will be most affected by alterations in atmospheric sulfate levels. (See Figures 6.8 and 6.9 in the main body of this study.)

Studies of visibility in relation to meteorological parameters have been performed by Renzetti, et al. (1955) and by Neiburger (1955). Documentation of the effects of high relative humidity on light extinction by Los Angeles smog aerosols is provided, and the variations of visibility with wind direction are discussed.

The relation of pollutant concentrations to visibility reduction has been explored. Early research efforts by the Los Angeles Air Pollution Control District led to the statement that,

> "It has been established that a significant percentage of the sulfur dioxide in the atmosphere oxidizes to sulfur trioxide. Preliminary evidence indicates that this acid mist could account for thirty to sixty percent of the total reduction in visibility." (Los Angeles Pollution Control District, 1950)[1]

Upon further study, the class of compounds in the aerosol phase potentially responsible for light extinction was found to be quite complex, including a wide variety of hygroscopic liquid droplets, carbon, "tar", opaque particles, plus soluble and insoluble transparent solids (Stanford Research Institute, 1954). The study of Renzetti, et al. (1955) attempted to correlate particulate loading of the atmosphere at Los Angeles and Pasadena with transmissometer measurements of visibility, but with limited success. The statistical section of that report showed that visibility was significantly negatively correlated with a wide variety of pollutant gases and other smog manifestations.

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[1] It is interesting to compare this statement with the fraction of light scattering at downtown Los Angeles attributed to SULFATES by White, Roberts and Friedlander (1975), as shown in Figure 6.3 in the main body of this study.

Undoubtedly some of the most interesting investigations are those which sought to relate pollutant emissions to visibility. In 1958, the Los Angeles Air Pollution Control District adopted Rule 62 which resulted in a rapid large scale change from high sulfur fuel use to natural gas combustion by industry in the Basin during the period May through September 1959 (Thomas, 1962). An improvement in visibility due to lowered levels of sulfur-bearing particulates was expected to accompany the $SO_2$ emission reductions. In a retrospective study of the effects of Rule 62 (Los Angeles Air Pollution Control District, 1959), little or no improvement in minimum visibility at Los Angeles or Burbank was noted. However, only data at 50 percent or lower relative humidities were considered.[2] At Los Angeles and Long Beach airports, which are closer to major point source locations, significant reduction in the number of days with minimum visibilities of about five miles or less at relative humidity of 60 percent or less was noted. Only about a 4 percent improvement in days of greater than ten-mile minimum visibility occurred at these airport locations. Another study prompted by Rule 62 was performed by Thomas (1962). He correlated visibility at downtown Los Angeles and Burbank, Long Beach and Los Angeles International airports with daily fuel oil consumption on days of poor meteorological dispersion. A small but statistically significant reduction in visibility due to fuel burning was found at Los

[2] At least over the decade following 1965 for which a nearly continuous record of sulfate data is available, days of high sulfate are significantly positively correlated with days of high relative humidity. (See Appendix D2, this chapter.) By discarding the data for observations above 50 percent relative humidity, many of the high sulfate days may have been overlooked by the LAAPCD.

Angeles International and Long Beach airports. At downtown Los Angeles and Burbank, there was no apparent negative correlation between visibility and fuel oil consumption. Neither of the above studies correlated atmospheric sulfate concentrations with visibility. The lack of visibility improvement at downtown Los Angeles was thus not demonstrated to have accompanied a drop in sulfate levels at that location.

## REFERENCES FOR APPENDIX D1

Kauper, E. K., R. G. Holmes, A. B. Street (1955), Visibility Studies, Los Angeles Air Pollution Control District Technical Paper No. 12.

Keith, R. W. (1970), Downtown Los Angeles Noon Visibility Trends, 1933-1969, Los Angeles Air Pollution Control District, Air Quality Report No. 65.

Keith, R. W. (1964), A Study of Low Visibilities in the Los Angeles Basin, 1950-1961, Los Angeles Air Pollution Control District, Air Quality Report No. 53.

Los Angeles Air Pollution Control District (1950), Technical and Administrative Report on Air Pollution Control in Los Angeles County, Los Angeles Air Pollution Control District Annual Report 1949-1950.

Los Angeles Air Pollution Control District (1959), Effects of Rule 62 - A Report of Evaluation.

Neiburger, M. (1955), Visibility Trend in Los Angeles, Los Angeles, Southern California Air Pollution Foundation Report No. 11.

Renzetti, N. A. et al. (1955), An Aerometric Survey of the Los Angeles Basin: August-November 1954, Los Angeles, Southern California Air Pollution Foundation Report No. 9.

Stanford Research Institute (1954), The Smog Problem in Los Angeles County.

Thomas, M. D. (1962), "Sulfur Dioxide, Sulfuric Acid Aerosol and Visibility in Los Angeles", Int. J. Air and Water Pollution, Vol. 6, pp. 443-454.

# APPENDIX D2

## VISIBILITY STUDY DATA PREPARATION

High volume sampler data on total suspended particulate, sulfate ion and nitrate ion concentrations at downtown Los Angeles was hand copied from the files of the LAAPCD. The period covered was August 1965 through December 1974. If duplicate samples were available for a 24-hour period, then the arithmetic mean of the two observations was recorded. Following White and Roberts (1975), it was assumed that SULFATES equals 1.3 times $SO_4^=$ concentration and NITRATES equals 1.3 times $NO_3^-$ concentration in order to account for the mass of associated cations. Each total suspended particulate (TSP) sample was then subdivided into SULFATES, NITRATES, and (TSP-SULFATES-NITRATES). All units are in micrograms per cubic meter. Data for days on which rain was recorded at downtown Los Angeles were discarded.

Hourly observations on prevailing visibility in miles, relative humidity as a fraction of complete saturation, and $NO_2$ concentration in ppm were extracted from LAAPCD data tapes. Data for days on which no corresponding particulate samples existed were discarded. Each remaining day's visibility data were examined, and only those days for which 9 hours of consecutive visibility observations existed were retained. Daily relative humidity and $NO_2$ data strings were then edited to retain only those hours for which a corresponding visibility observation existed. Since the $NO_2$ instrument was typically

recalibrated around noontime daily, at least one hour of missing $NO_2$ data was embedded in each $NO_2$ data string corresponding to consecutive visibility observations. Missing hourly $NO_2$ and relative humidity data corresponding to available visibility observations were replaced by the linear interpolation between adjacent valid data points. If more than three embedded consecutive hourly observations were missing, the day's data were discarded. Missing end points in the $NO_2$ and relative humidity data strings were replaced by the adjacent value. If the next point adjacent to a missing end point was also missing, the day's data were discarded. The atmospheric extinction coefficient at each hour, $b_i$, was then estimated from prevailing visibility at that hour by equation (6.9). Finally the t hour average (nominally t = 9) of the extinction coefficient, $NO_2$ concentration ($\overline{NO_2}$), and relative humidity ($\overline{RH}$) was taken for each day of interest. It is important to note at this point that the average extinction coefficient computed in this manner is <u>not</u> equal to the inverse of the average of the day's prevailing visibility observations scaled in proportion to the constant of equation (6.9). For use in forming the non-linear functions of relative humidity in equation (6.19), each hourly relative humidity value, $RH_i$, was retained. At the end of this editing process, 413 days of useful data on all selected variables remained spanning the period August 1965 through December 1974.

A second data base for use with the low humidity model was constructed by a similar procedure. In this case, however, hourly extinction coefficient, $NO_2$, and relative humidity observations were

edited prior to averaging to remove all data for those hours where relative humidity exceeded 70 percent. If fewer than five hours of low humidity observations remained in a day after this editing procedure, the day's data were discarded. In this second data base, 390 days of observation on all selected variables remained spanning the period August 1965 through December 1974. A statistical description of these data bases follows.

# TABLE D2.1

## Statistical Description of the Data Used in the Visibility Study (Unrestricted Data Base Incorporating all Relative Humidity Values)

Number of Complete Sets of Observations = 413 Days

Time Period Spanned is August 1965 through December 1974

Variable

| | Average** Extinction Coefficient | SULFATES* | NITRATES* | (TSP-SULFATES -NITRATES)* | $NO_2$** | Average** Relative Humidity | DUMMY |
|---|---|---|---|---|---|---|---|
| | $[10^4\ m]^{-1}$ | $\mu gm/m^3$ | $\mu gm/m^3$ | $\mu gm/m^3$ | ppm | %/100 | one or zero |
| Average | 6.62 | 17.54 | 13.92 | 127.18 | 0.100 | 0.53 | 0.52 |
| Standard Deviation | 5.52 | 14.80 | 10.77 | 50.59 | 0.050 | 0.17 | 0.50 |

Correlation between Variables

| | Extinction Coefficient | SULFATES | NITRATES | (TSP-SULFATES -NITRATES) | $NO_2$ | RH%/100 | DUMMY |
|---|---|---|---|---|---|---|---|
| Extinction Coefficient | 1.00 | 0.62 | 0.09 | 0.25 | 0.42 | 0.38 | 0.11 |
| SULFATES | 0.62 | 1.00 | -0.03 | 0.08 | 0.22 | 0.48 | -0.17 |
| NITRATES | 0.09 | -0.03 | 1.00 | 0.29 | 0.42 | -0.14 | -0.21 |
| (TSP-SULFATES -NITRATES) | 0.25 | 0.08 | 0.29 | 1.00 | 0.48 | -0.29 | 0.14 |
| $NO_2$ | 0.42 | 0.22 | 0.42 | 0.48 | 1.00 | -0.14 | -0.15 |
| RH%/100 | 0.38 | 0.48 | -0.14 | -0.29 | -0.14 | 1.00 | -0.11 |
| DUMMY | 0.11 | -0.17 | -0.21 | 0.14 | -0.15 | -0.11 | 1.00 |

*24 hour average.

**t hour average, where t corresponds to the 9 hours of visibility observations available in each day selected.

TABLE D2.2

Statistical Description of Data Used in this Visibility Study
(Restricted Data Base Incorporating only those Hours with
Relative Humidity Below 70%)

Number of Complete Sets of Observations = 390 Days

Time Period Spanned is August 1965 through December 1974

Variable

| | Average** Extinction Coefficient | SULFATES* | NITRATES* | (TSP-SULFATES -NITRATES)* | $NO_2$** | Average** Relative Humidity | DUMMY |
|---|---|---|---|---|---|---|---|
| | $[10^4\ m]^{-1}$ | $\mu gm/m^3$ | $\mu gm/m^3$ | $\mu gm/m^3$ | ppm | %/100 | one or zero |
| Average | 5.65 | 16.30 | 14.28 | 129.47 | 0.099 | 0.48 | 0.51 |
| Standard Deviation | 3.83 | 13.83 | 10.70 | 50.37 | 0.052 | 0.14 | 0.50 |

Correlation between Variables

| | Extinction Coefficient | SULFATES | NITRATES | (TSP-SULFATES -NITRATES) | $NO_2$ | RH%/100 | DUMMY |
|---|---|---|---|---|---|---|---|
| Extinction Coefficient | 1.00 | 0.67 | 0.11 | 0.39 | 0.52 | 0.31 | 0.12 |
| SULFATES | 0.67 | 1.00 | 0.003 | 0.14 | 0.24 | 0.44 | -0.13 |
| NITRATES | 0.11 | 0.003 | 1.00 | 0.26 | 0.39 | -0.07 | -0.25 |
| (TSP-SULFATES -NITRATES) | 0.39 | 0.14 | 0.26 | 1.00 | 0.47 | -0.25 | 0.14 |
| $NO_2$ | 0.52 | 0.24 | 0.39 | 0.47 | 1.00 | -0.13 | -0.14 |
| RH%/100 | 0.31 | 0.44 | -0.07 | -0.25 | -0.13 | 1.00 | -0.12 |
| DUMMY | 0.12 | -0.13 | -0.25 | 0.14 | -0.14 | -0.12 | 1.00 |

*24 hour average.

**t hour average, where t = number of hours of visibility observations available that day; nominally t = 9; $t_{min} = 5$.

# APPENDIX D3

## SUMMARY OF NEIBURGER AND WURTELE'S APPROXIMATION RELATING PARTICLE SIZE TO PARTICLE SOLUTE MASS

Light scattering by aerosols is a strong function of particle size. Particle size in turn is heavily influenced by atmospheric humidification if the aerosol material is water soluble.

Relative humidity is defined as the prevailing ambient vapor pressure of water divided by the saturation vapor pressure over a plane pure water surface at the same temperature. Three factors altering the equilibrium vapor pressure over atmospheric droplets from that prevailing over a plane pure water surface are surface curvature, electric charge and dissolved substances. The effect of surface curvature is to raise the equilibrium vapor pressure while the effect of electric charge and dissolved substances is to lower it. If the solution effect dominates, then droplets containing liquid water can persist in the atmosphere at relative humidities below 100 percent.

Neiburger and Wurtele (1949) examined these factors as they affect atmospheric solution droplets of approximately one micron particle diameter. They conclude that the vapor pressure lowering effect of the dissolved substances in such particles will control particle size at humidities below 100 percent. Relying on laboratory data for vapor pressure over solutions of electrolytes, they constructed an expression for the vapor pressure over a solution droplet:

$$\frac{p}{p_o} = 1 - CM \tag{D3.1}$$

where

$p$ = the vapor pressure of water over a solution droplet.

$p_o$ = the vapor pressure over a plane surface of pure water.

$M$ = concentration of solute in the droplet, expressed as gram formula weights of solute per gram of solution.[1]

$C$ = a factor which can be computed from experimental data presented in the International Critical Tables. C is not a constant; rather it is a function of concentration, temperature, and the nature of the solute involved.

For the droplet to remain in equilibrium in the atmosphere, the left-hand side of equation (D3.1) is equated to the ambient relative humidity, RH, as follows:

$$RH = 1 - CM \tag{D3.2}$$

The mass concentration of solute in the drop is given by:

$$c = wM \tag{D3.3}$$

where

$c$ = mass concentration of solute in the drop expressed as grams of solute per gram of solution.

$w$ = solute molecular weight, in grams per gram formula.

The mass of solute in one drop is related to its mass concentration, c, by:

$$m_s = \frac{4}{3} \pi r^3 \rho c \tag{D3.4}$$

---

[1] The system of units used in Neiburger and Wurtele's paper was not spelled out explicitly. In this recapitulation of their argument, a set of consistent units is supplied. Please note that this unit system differs from that used in the International Critical Tables, and that M as used in (D3.1) is based on solution weight, not solvent weight.

where

$m_s$ = mass of solute in the droplet, grams.

r = droplet radius, in centimeters.

$\rho$ = droplet density, grams of solution per cubic centimeter.

Solving equation (D3.4) for c:

$$c = \frac{3}{4}\frac{m_s}{\pi r^3 \rho} \tag{D3.5}$$

Substituting equations (D3.5) and (D3.3) into equation (D3.2), Neiburger and Wurtele developed an expression for droplet radius:

$$r = K[m_s/(1-RH)]^{1/3} \tag{D3.6}$$

The factor $K = (3C/4\pi\rho w)^{1/3}$ was described by Neiburger and Wurtele as "... a parameter of the nuclear substance which has a variation of the order of 1 percent with temperature and concentration." Checking that statement as it applies to solutions of ammonium sulfate and ammonium nitrate, one finds that K is not quite that well behaved. For ammonium nitrate at a reference temperature of 100°C, K decreases by roughly 10 percent as the concentration of solute in the solution is diluted from 24 molal down to about 0.6 molal. The change in $K^3$, for example, would be correspondingly more pronounced. Still, the order of magnitude of the change in K seems small compared to the order of magnitude of changes in solute concentration.

The reader should thus be cautioned that the assumption that K is constant is an empirically-based approximation. This approximation is attractive because it yields an uncomplicated hyperbolic expression in relative humidity which is practical for use in a simple non-linear

regression model while at the same time preserving some sense of the underlying relationship between particle size and light scattering. For a theoretically-based discussion relating the particle size of solution droplets to ambient relative humidity, see Byers (1965). The reader might also be interested in a recent review article by Hänel (1976) which explores the relationship between theoretical and approximate treatments of particle size as a function of relative humidity.

## REFERENCES FOR APPENDIX D3

Byers, H. R. (1965), Elements of Cloud Physics, Chicago, The University of Chicago Press.

Hänel, G. (1976), "The Properties of Atmospheric Aerosol Particles as Functions of the Relative Humidity at Thermodynamic Equilibrium with the Surrounding Moist Air," in Landsberg, H. E. and J. Van Mieghem, Advances in Geophysics, Volume 19, New York, Academic Press (1976).

International Critical Tables (1928), Vol. III, New York, McGraw-Hill, p. 292 and following.

Neiburger, M. and M. G. Wurtele (1949), "On the Nature and Size of Particles in Haze, Fog and Stratus of the Los Angeles Region," Chemical Reviews, Vol. 44, No. 2, April (1949).

# APPENDIX D4

## SUMMARY OF RECOMMENDATIONS FOR DESIGN OF ROUTINE AIR MONITORING PROGRAMS AIMED AT ASSESSMENT OF THE CAUSES OF VISIBILITY DETERIORATION

### D4.1 Introduction

Analysis of existing air pollution control agency routine air quality measurements is not only cost-effective; it is usually the only way in which one can say anything about the long-term behavior of an air basin without designing an experiment from scratch and then waiting for the long-term to repeat itself. However, air pollution control agency air monitoring programs usually have not been designed with a visibility study in mind. In attempting to use existing data to reveal the relationship between sulfate air quality and visibility deterioration at a particular air monitoring site, a number of difficulties were encountered and tackled. Comments made in passing on the means for eliminating some of these difficulties are summarized in this appendix.

### D4.2 Particle Size Determination

As shown in Figure 6.1 of this study, the light scattering potential of a given mass of atmospheric particulate matter is a strong function of particle size. Particles in sizes between one-tenth microns and two microns in diameter are responsible for the bulk of the light scattering in the Los Angeles atmosphere. In this study, aerosol chemical composition has been used as a key to particle size and solubility. It would be more desirable, however, to obtain data on particle

size directly from physical measurements. This can be done by incorporation of inertial impactors into an agency's air monitoring program. Before beginning a size-segregated particulate sampling program, a careful intermethod study would be necessary to select or design an impactor with a sharp cut-off between adjacent stages, and a high enough flow rate to collect a sample volume suitable for chemical analysis.

D4.3 Chemical Resolution

In this study, the results of comprehensive chemical analysis of particulate samples taken from the Los Angeles atmosphere as part of previous short-term special studies (e.g., those of Hidy, et al, 1975) served as a pre-survey of the important chemically distinguishable fractions of the local submicron aerosol. Before establishing visibility analysis as one of the goals of its particulate sampling program, an agency should assure itself that data will be collected on all of the abundant submicron chemical species. For example, in the study performed as part of this research effort, the lack of availability of ammonium ion and organic particulate data required that major assumptions be made (based on the findings of others) before the analysis could proceed. When a pre-survey indicates that additional important pollutants require measurement before the visibility study's success can be assured, then the agency should consider allotting resources sufficient to develop laboratory practices and capacity for performing those analyses.

Once the monitoring program is underway, it should be possible to check the chemical measurements against visibility observations to see

if any unexpected relationships hint at sampling trouble. In the case of the study pursued in Chapter 6 of this report, a near zero correlation between NITRATES and extinction coefficient, plus an exaggerated estimate of the extinction coefficient per ppm for $NO_2$, indicate a possible problem with sample collection or analysis which should be investigated further.

### D4.4 Temporal Resolution

A visibility study requires simultaneous information on particulate characteristics, nitrogen dioxide data, relative humidity information, and an estimate of the atmospheric extinction coefficient. Air monitoring and meteorological data bases should be designed so that each necessary measurement can be computed over the same averaging time. Ideally, one would like periodic instantaneous readings on each variable of interest, but that is not feasible with present particulate sampling technology. Data taken over two-hour averaging times by Hidy, et al. (1975) allowed White and Roberts (1975) to obtain excellent statistical confidence tests in their visibility study. At longer averaging times, information can still be extracted from a statistical study of visibility in relation to aerosol composition, but the unexplained variance in regression model results will possibly increase. Increased sampling frequency is of course more expensive. Perhaps intensive short-term sampling should be confined to a few monitoring stations at which the meteorological measurements needed by a visibility study are also readily available.

D4.5 Extinction Coefficient Determination

Visual range and extinction coefficient estimates can be made either by instrumental methods or a human observer. Each of these approaches has its own advantages and disadvantages. However, if one wishes to use these measurements interchangeably, it is important to run a comparative study between the agency's trained observer and instrumentally determined $b_{scat}$ values. As mentioned in the body of this report, less than ideal availability of visibility markers, plus the requirement that markers be clearly recognized and not just seen could lead to a minimum contrast level for reported prevailing visibility observations that deviates from Koschmieder's assumptions.